The Value of Signals for Reward:

Choice in Concurrent Chains

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ABSTRACT

A number of studies indicate that a signalling effect occurs when stimuli are presented during the terminal link of a concurrent-chains procedure, which signal whether or not probabilistic reinforcement is forthcoming at the end of the trial. The effect of these signals is a reduced preference for the richer alternative. This thesis includes five experiments aimed to investigate this. The overall purpose of this research is to investigate the effect on preference of differential signalling of reinforcement that differs in terms of the variable being signalled. Furthermore, these experiments are aimed at investigating the manner in which signalling affects preference when multiple dimensions of reinforcement are varied in a signalling procedure. Asking the question, how does signalling affect sensitivity to various dimensions of reinforcement and how does this change when more than one dimension is varied?

The first experiment involved a simple replication of previous work with percentage-reinforcement procedures. It further extends that work by signalling the size of the reinforcer rather than its probability. Pigeons were given the choice between two alternatives with identical-duration initial and terminal links. Choice of one alternative (uncertain) led to one of two possible signalled outcomes, reinforcement (3.5 s) or blackout, with a probability of .5. Choice of the other alternative (certain) always resulted in food (3.5 s) at the end of the delay. When the scheduled outcome on the uncertain alternative was differentially signalled, there was a moderate preference for the certain side. Moreover, when the scheduled outcome

on the uncertain side was not differentially signalled, preference for the certain side became more extreme. This result replicates the signalling effect. With a similar design, another three conditions manipulated the magnitude of primary reinforcement, rather than its probability. When primary reinforcement was arranged like this, a weaker signalling effect was obtained.

Two further experiments investigated the effect of signals on preference for alternatives that differed in either relative variability or expected magnitude of reinforcement, while the other variable was held constant. In Experiment 2, pigeons were offered the choice between two alternatives that differed in relative variability of reinforcement. Each alternative delivered one of two possible reinforcer magnitudes at the end of a terminal link: these magnitudes were either the same (fixed) or were different (mixed). In some conditions, terminal-link outcomes were signalled and in others they were not. Results showed that pigeons preferred fixed over signalled mixed magnitudes of reinforcement, and signalled mixed over unsignalled mixed magnitudes of reinforcement. Thus, these alternatives could be ordered in terms of preference: fixed, signalled mixed and unsignalled mixed. Finally, signalling does indeed moderate the preference for fixed over mixed magnitudes.

In the third experiment, pigeons completed a two-component signalled concurrent-chains procedure in which the relative expected magnitude varied across alternatives as all other dimensions of reinforcement were held constant. Therefore, this experiment investigated the effects of signalling on preference between alternatives differing in relative expected magnitude of reinforcement. A slight signalling effect was obtained, with slightly reduced preference in the signalled

relative to the unsignalled condition. Overall, these two experiments confirm that signalling acts on the preference for fixed magnitudes of reinforcement and to a lesser extent, preference for the larger of two expected magnitudes of reinforcement.

The final two experiments investigated the effect of signals on preference in a procedure that varied parametrically either relative probability and immediacy of reinforcement, or probability and magnitude of reinforcement. The effects of relative reinforcer immediacy or magnitude and probability on choice in concurrent chains were examined, under conditions in which terminal-link outcomes (reinforcement or extinction) were either signalled or unsignalled. Pigeons responded in a three-component concurrent-chains procedure with either independent or interdependent initial links. The percentage of reinforcement was varied across conditions, while the immediacy or magnitude of reinforcement was varied across components. Both signalled and unsignalled conditions were arranged. Generalised-matching analyses revealed a strong signalling effect: sensitivity to relative reinforcer probability was greater in the unsignalled compared to signalled conditions. However, sensitivities to relative immediacy and magnitude were also greater in the unsignalled conditions. Overall, the data suggest that signalling reinforcement and extinction outcomes may attenuate sensitivity to all terminal-link variables, not just reinforcer probability.

These experiments have investigated the signalling effect using a variety of methods. They have contributed several replications of the effect, and added valuable information regarding the effects on preference of signalling reinforcement outcomes. The most impressive finding of this research is that signalling has a global effect on

sensitivity to all dimensions of reinforcement and that models of conditioned reinforcement are best suited to analyse these results.

CHAPTER 1: GENERAL INTRODUCTION

1.1: The study of preference

The experimental analysis of behaviour investigates many aspects of human and animal behaviour. One of these areas is choice and of particular importance is how we study preference in non-verbal animals. One means of studying preference is to offer choices that differ in relation to their consequences. For example, a subject might be given the choice between a smaller and a larger reinforcer. We measure preference by assessing the distribution of responses (or time) to each alternative. If more responses are allocated to one alternative relative to the other, it is said that the subject prefers that alternative. One would expect that in this example the subject would distribute most of its responses to the alternative providing the larger reinforcer.

A specific example of a procedure for studying choice is the concurrent schedules procedure. As indicated above, the typical procedure involves a choice between two alternatives that differ in the reinforcement associated with each. Often different stimuli are used to signal each alternative, so that one response key might be illuminated with a red light and the other a green light. There is an assumption that subjects will choose between the two alternatives equally (i.e., be indifferent between the two) if the dimensions of reinforcement associated with each are equal.

The concurrent-schedules procedure involves simultaneous presentation of two or more independent schedules, each leading to reinforcement. A common schedule of reinforcement used in this procedure is the Variable Interval (VI) schedule. The interval begins with the key lights being illuminated and is completed when reinforcement is delivered. As the name suggests, the time to reinforcement is variable. For example, a VI 30 s reinforcement schedule has a mean interval of 30 s, however on any given trial the interval varies depending on the particular progression (i.e., arithmetic, exponential) that is used. Reinforcement is often arranged non-independently (i.e., Stubbs & Pliskoff, 1969), where a single timer times the interval to reinforcement for both alternatives. Timing stops when a reinforcer is arranged for one alternative, and re-starts for both alternatives once the reinforcer has been delivered.

A feature often employed in concurrent schedules is an enforced limitation on switching between the two alternatives. This is achieved by including a change-over delay (COD), which essentially punishes switching. Specifically, after switching from one alternative to the other, reinforcement will not be available for x seconds after the change was made. This provides a contingency against continual switching between the two alternatives, and thus permits a better estimate of preference (e.g., Herrnstein, 1961, 1970).

In the quantitative analysis of behaviour, many theories and mathematical models of choice have developed over time. Their common goal is to provide an adequate description of behaviour that will enable prediction of future behaviour. The matching law is probably the most widely known of these theories. The matching law

describes the relationship between (choice) behaviour and various dimensions of reinforcement, such as reinforcer rate, reinforcer magnitude and delay to reinforcement. These dimensions can be considered 'determiners of choice' because of their influence over behaviour. In the following sections, several determiners of choice will be discussed in the context of the matching law.

1.2: The Matching Law and Rate of Reinforcement

Herrnstein (1961) was the first to report a matching relation between relative response distribution and relative reinforcement. It has subsequently become known as The Matching Law. Herrnstein, using an independent concurrent VI schedule, found that relative response rate (or choice) closely matched the relative reinforcement rate. Specifically, the distribution of responses between the two alternatives closely matched the distribution of reinforcement on each alternative. Thus, Herrnstein identified relative reinforcement rate as a determiner of choice.

The matching relation can be expressed as follows in Equation 1.1, where P is the number of pecks, R is the rate of reinforcement and the subscripts 1 and 2 represent the left and right alternatives, respectively.

$$\frac{P_1}{P_1 + P_2} = \frac{R_1}{R_1 + R_2} \tag{1.1}$$

Of note, when there was no COD in effect, almost perfect alternation between the two alternatives was found - the distribution of responses remained at approximately 50/50 regardless of the scheduled reinforcement at each alternative (Herrnstein, 1961). When the COD was introduced (i.e., Herrnstein, 1961, 1964), the rate of changeover dramatically reduced, and the matching relation became apparent. Thus, he concluded that the COD enhances control of relative response rate by relative reinforcement, by reducing the level of switching between alternatives. Herrnstein (1970) reviewed previous research and sought to investigate whether the strength of the matching relation was a function of the duration of the COD. He found that there were no systematic variations in matching dependent on the duration of the COD, so long as the COD was longer than a minimal duration.

Fantino, Squires, Delbrück and Peterson (1972) also investigated duration of the COD as an influence on choice behaviour. They manipulated both relative and absolute rate of reinforcement using simple concurrent schedules. They found moderate preference for the richer alternative across the three absolute reinforcer rates used, when a 1.5 s COD was used. One exception was noted, where near exclusive preference was found for the richer alternative with the shortest absolute inter-reinforcer-interval (conc. VI 6 s VI 12 s). This preference was greatly reduced when the COD became proportional to the absolute inter-reinforcer-interval (i.e., 0.15 s). They concluded that choice proportions were determined by both the relative rate of reinforcement and by the absolute inter-reinforcer-interval.

In summary, matching to relative reinforcement has been observed in a number of studies. As commonly occurs in the experimental analysis of behaviour,

once a phenomenon has been established, researchers seek to push the limits to assess the generality of the effect. The next section will discuss generalisation of the matching law, addressing the question of whether the matching law will apply when other dimensions of reinforcement are manipulated, such as magnitude and delay of reinforcement, instead of reinforcement rate.

1.3: Generalisation of the matching law

Since Herrnstein (1961), matching has been found in numerous experiments. For example, Catania (1963) found matching when he varied relative magnitude of reinforcement; Chung and Herrnstein (1967) found matching to relative delay of reinforcement; Neuringer (1967) found matching to relative total access to food; and Herrnstein (1964) reported that the matching law could also describe preference in concurrent chains (but see later). Many of these studies have tested the generality of the matching law and have sparked debate regarding its predictions.

Baum and Rachlin (1969) and Baum (1974) noted consistent deviations from strict matching (i.e., Equation 1.1). Baum and Rachlin generalised the matching law by including a bias parameter, k (see Equation 1.2); defining bias as a constant proportionality in behaviour favouring one alternative over the other. Essentially, bias is unaccounted for preference: it is virtually impossible to measure or control all independent variables. Baum (1974) suggested four possible reasons for bias. These included response bias (e.g., unequal response force requirements), discrepancy between scheduled and obtained reinforcement, qualitatively different reinforcers, and qualitatively different schedules. Furthermore, Baum noted that sometimes the level

of preference expressed by the behaviour ratio is not as extreme as strict matching (i.e., Equation 1.1) would predict. This led to further generalisation of the matching law by including a sensitivity parameter, a. This measure indicates the sensitivity of behaviour to changes in relative reinforcement.

$$\frac{B_1}{B_2} = \kappa\left(\frac{R_1}{R_2}\right)^a \tag{1.2}$$

When the function is expressed logarithmically (Equation 1.3), a represents the slope of the line (or sensitivity) and log k represents the y-intercept (or bias).

$$\log\frac{B_1}{B_2} = a\log\left(\frac{R_1}{R_2}\right) + \log\kappa \tag{1.3}$$

According to Baum (1979), sensitivity values often fall below one (i.e., $a < 1$). This is known as undermatching, where the level of preference falls below what is expected according to the matching law. Baum suggested that undermatching might be caused by certain patterns of responding. These included asymmetrical pausing favouring the poor alternative, systematic temporal variation in preference that favours the poor alternative and patterns in responding that involve changing over. Overmatching may also occur, when the level of preference is greater than what the matching law predicts (i.e., $a > 1$).

The generalised matching law has been shown to adequately describe behaviour allocation in concurrent schedules (Alsop & Elliffe, 1988; Baum, 1979; Davison & McCarthy, 1988; Wearden & Burgess, 1988). For example, Alsop and

Elliffe (1988) found that the generalised matching law was a useful descriptor of concurrent schedule choice behaviour. They arranged concurrent non-independent VI VI schedules that varied across six sets of conditions. The overall rate of reinforcement was constant in each set but varied across sets (ranging from 0.22 to 10 reinforcers per minute). The ratio of reinforcers was varied through the same range (8:1 to 1:8) for each set. Overall response rates decreased with decreases in overall reinforcement rate, but did not change with relative rates. Moreover, sensitivity to reinforcer frequency decreased as overall rate decreased. Changes in behaviour as absolute reinforcement varied is not predicted by the matching law, as it is a statement regarding *relative* behaviour and reinforcement. In general however, the data presented by Alsop and Elliffe support the generalised matching law as a descriptive tool for behaviour in concurrent schedules.

By this time it was widely accepted that relative reinforcement determines relative behaviour, and that subjects could be differently sensitive to different dimensions of reinforcement. Interest turned to what would happen when more than one dimension of reinforcement was varied simultaneously. Could the matching law be adjusted to deal with such variations, and would it still provide an adequate description of the relationship between reinforcement and behaviour? In order to answer such questions, the form of the matching law would need to change again, to include all possible dimensions of reinforcement: hence the concatenated matching law.

1.4: The Concatenated Generalised Matching Law

A further generalisation of the matching law recognises that many dimensions of reinforcement combine to influence choice. Baum and Rachlin (1969) found that relative time spent on each side of the chamber (in addition to relative response rate) could be predicted by the matching law. They suggested that the matching law governs time allocation and this in turn reflects the value attached to each alternative by the subject. They subsequently extended the matching relation to define 'value' of reinforcing outcomes; thus developing the Concatenated Matching Law (CML). The CML states that the *value* of an alternative is affected equally and multiplicatively by all dimensions of reinforcement, i.e., rate, amount and immediacy. They re-expressed the matching function by concatenating these various dimensions of reinforcement. In Equation 1.4, B is behaviour or pecks, k represents bias, R is rate of reinforcement, M is magnitude of reinforcement, $1/D$ is the immediacy of reinforcement and V is the value of each alternative. Again, the subscripts 1 and 2 represent the choice alternatives.

$$\frac{B_1}{B_2} = k\left(\frac{R_1}{R_2}\right)\cdot\left(\frac{1/D_1}{1/D_2}\right)\cdot\left(\frac{M_1}{M_2}\right) = \frac{V_1}{V_2} \qquad (1.4)$$

It can also be generalised (see Equation 1.5) to account for undermatching and bias. In the generalised version it is recognised that the value of an alternative may not be affected equally by all dimensions of reinforcement, and thus the generalised form allows different sensitivity values for different dimensions. The generalised concatenated matching law combines three versions of the matching law – the original

matching law (Equation 1.1), the generalised matching law including the two parameters, a and k (Equation 1.2) and the CML (Equation 1.4). In Equation 1.5, a_r, a_m and a_d are the sensitivity values for reinforcement rate, amount and delay respectively, and k is the bias measure,

$$\log\frac{B_1}{B_2} = a_r \log\left(\frac{R_1}{R_2}\right) + a_d \log\left(\frac{1/D_1}{1/D_2}\right) + a_m \log\left(\frac{M_1}{M_2}\right) + \log k \qquad (1.5)$$

1.4.1: Assumptions of the Concatenated Matching Law

By combining dimensions of reinforcement into one equation, a number of assumptions are made regarding the relationship between each dimension. Specifically, there are two underlying assumptions of the Concatenated Matching Law: the relativity assumption, and the independence assumption (Killeen, 1972).

The relativity assumption concerns the fact that the matching law is based on relative values. Thus, it is assumed that *absolute* values on any dimension of reinforcement should not affect choice. However, many studies, (including Alsop & Elliffe, 1988, described above) have found that preference is affected by absolute values of reinforcement. Logue and Chavarro (1987) investigated the relativity assumption in a number of experiments by varying one dimension of reinforcement (delay, amount or frequency) while keeping the others constant. In these experiments, the absolute (but not relative) value of one dimension of reinforcement was varied. They used short, non-independent concurrent VI VI schedules that controlled relative reinforcer frequency. In each of their three experiments, the reinforcer ratios of delay,

amount and frequency were held constant at 3:1. With a reinforcer ratio of 3:1, the matching law predicts a preference of 3:1 for the rich alternative, assuming that absolute values do not affect choice. The data showed that there were significant and orderly changes in preference as the absolute (but not relative) values of reinforcement were varied. For amount and frequency of reinforcement there was a significant decrease in preference for the rich alternative as the absolute values increased, and a significant increase in preference for the rich alternative as absolute delay increased. This suggests that absolute values of reinforcement do affect choice, thus the relativity assumption of the CML is violated.

Data from Alsop and Elliffe (1988) also provided evidence against the relativity assumption. They found that sensitivity to relative reinforcer frequency decreased as absolute rate decreased: preference became less sensitive to relative reinforcement as overall reinforcer rate decreased. Thus, changes in absolute reinforcer rate affect relative sensitivity, which is also in violation of the relativity assumption.

The second assumption, the independence assumption, also arose out of concatenating the reinforcement variables because it is assumed that each are unaffected by relative values of others, i.e., they have independent effects on behaviour. According to the independence assumption, sensitivity to changes in one dimension of reinforcement should be unaffected by changes in another dimension of reinforcement. Is this really the case?

Davison (1988) investigated this assumption using a concurrent VI VI schedule. The duration of the VI schedules varied over conditions (from VI 32 s to 480 s), although the average duration across alternatives was equal. He used constant but different reinforcer durations on each alternative, where the left alternative provided 10 s access to reinforcement and the right, three second access. The conditions were arranged in this way to measure changes in sensitivity to relative reinforcement magnitude, while varying absolute frequency of reinforcement. He reported that as absolute reinforcer rate increased, preference for the larger reinforcer decreased to approximately indifference. Thus, preference between different reinforcer magnitudes may not be independent of the absolute frequency of reinforcement. In terms of the generalised matching law, this meant that sensitivity to magnitude (a_m) fell as absolute frequency increased. Davison thus concluded that the generalised matching law has difficulty dealing with interactions between various parameters of reinforcement.

If interactions between dimensions of reinforcement occur, then each dimension does not have independent effects on behaviour. If this is indeed the case, then the adequacy of the concatenated matching law as a complete quantitative model of choice needs to be questioned. However, the principle that all dimensions of reinforcement combine to influence choice is appealing and has gained much support in the literature. Thus, the matching law (and its subsequent generalisations) has continued to be a dominant force in the quantitative analysis of behaviour. Again, the quest for generality led researchers to apply this law to other experimental procedures, specifically to the concurrent chains procedure. The following section includes a description of the concurrent chains procedure, application of the matching law to

concurrent chains and delay of reinforcement as a determiner of choice, and the various models that have developed out of this line of research.

1.5: Concurrent chains

Research into the generality of the matching relation has been ongoing since its emergence. Another example of this is Herrnstein (1964) who applied it to the concurrent chains procedure. The concurrent chains procedure was introduced by Autor (1960, 1969) in order to assess the preference for different reinforcement schedules. It was later refined to assess whether the matching law could describe relative response distributions maintained by conditioned rather than primary reinforcement; i.e., use in concurrent chains (Herrnstein, 1964). In simple concurrent schedules, the rate of responding generated by each schedule confounds the measure of preference. Different schedules of reinforcement can generate different rates of responding, independently of reinforcer rate; for example, a Variable Ratio (VR) schedule generates a high rate of responding while in a Fixed Interval (FI), response rate is much lower (Davison, 1969). If the relative rate of responding were taken as a measure of preference, it would favour the VR schedule simply because of the faster responding it generates. However, in concurrent chains, two different schedules can be assessed concurrently and independently, as the measure of choice (initial-link relative response rate) is isolated from the schedules that are being chosen. Thus, the concurrent chains procedure is an informative experimental design for studying such choice as it allows many variables (such as delay to or magnitude of reinforcement) and schedules to be studied independently and simultaneously, without the confound described above.

The concurrent chains design (see Figure 1.1) is similar to standard concurrent schedules where two concurrently available schedules of reinforcement are offered to the subject on two response keys. However, the concurrent chains procedure is separated into two parts – the initial link (choice phase) and the terminal link (outcome phase). In the initial link, response keys are often illuminated by the same coloured light (white in Figure 1.1). Responding in the initial link permits access to one two mutually-exclusive terminal links, where another stimulus is presented that is correlated with that terminal link (green or red in Figure 1.1). Once a terminal link has been entered, the other key becomes dark and inoperative. After completion of the terminal link, reinforcement is sometimes delivered according to the terminal link schedule.

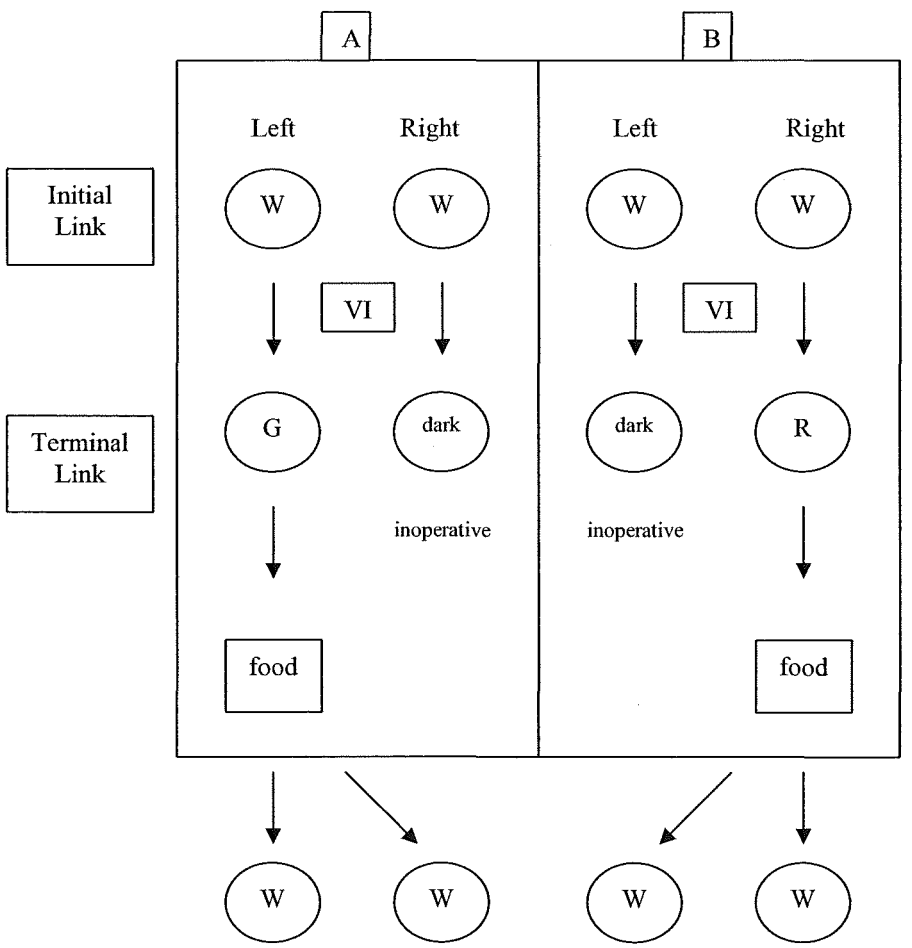

Figure 1.1: The concurrent chains procedure.

In Figure 1.1, Section A shows a trial where the left terminal link is entered and subsequent reinforcement delivered, whereas Section B shows a trial where the right terminal link is entered and subsequent reinforcement delivered. The concurrent-chain procedure introduces delay to reinforcement (i.e., the terminal-link duration) as a determiner of choice. By varying the relative delay to reinforcement on each alternative, the study of preference and delay is permitted.

1.6: Delay to reinforcement as a determiner of choice

Delay is a dimension of reinforcement that has been well researched. Of particular importance here is the degree to which delay to reinforcement is a determiner of choice, and how the matching law describes preference for various delays. Thus far, both rate and magnitude of reinforcement have been shown to be determiners of choice. Can the same be said for delay (or immediacy, the reciprocal of delay,) to reinforcement, and how do variations in delay influence preference?

Chung (1965) used a two-key concurrent schedule with one alternative offering immediate reinforcement ("standard" key) while the other offered reinforcement after a delay ("experimental" key). He found that both absolute and relative response rates on the experimental alternative decreased with increasing delays on that key. This suggests that delayed reinforcement decreases the value of an alternative.

In a similar experiment, Chung and Herrnstein (1967) offered pigeons the choice between two alternatives differing in delay to reinforcement. Overall, they

found that relative frequency of responding was a joint function of the delay on both alternatives: preference favoured the experimental alternative when the delay to reinforcement on it was shorter than the delay on the standard alternative. As the delay on the experimental alternative increased, the proportion of responses to that alternative decreased until subjects chose the standard alternative almost exclusively. They reported that relative response rate matched relative immediacy of reinforcement, which is consistent with the predictions of the matching law. However, they also reported a tendency toward overmatching.

These two studies have established relative immediacy of reinforcement as a feature of reinforcement that influences behaviour in a manner consistent with predictions of the matching law – when using concurrent schedules. However, inconsistencies in more recent literature – using concurrent chains – question relative immediacy of reinforcement as the sole determiner of choice, and question the simple application of the matching law as an adequate model of choice. In particular, research indicates that initial- and terminal-link schedules affect choice; this is not accounted for by the matching law.

The Initial-Link Effect

Fantino (1969) investigated the effect on preference of the initial-link duration. He hypothesised that as the initial-link duration increased, relative differences in the terminal-link schedules of reinforcement should have less influence over preference (Fantino, 1969). Results supported his hypothesis: preference became less extreme as initial-link duration increased. Davison (1983) maintained that the concatenated generalised matching law (CGML) could be applied to data from a concurrent-chains

procedure. However, two phenomena could upset a simple application: the initial-link effect and the terminal-link effect. Davison found that sensitivity to relative reinforcer rate varied as a function of initial- and terminal-link durations. Thus, he demonstrated that the temporal context of reinforcement (within concurrent chains) influences preference. Fantino and Davison (1983) also found that preference became less extreme as initial-link duration increased. This change in preference with change in initial-link duration has become known as the 'initial-link effect'.

The Terminal-Link Effect

In a further test of the generality of the matching law, MacEwen (1972) investigated terminal-link schedules of various relative and absolute durations. A single VI schedule was used in the initial links to ensure equal entry into both terminal links. He used both FI and VI schedules in the terminal links, varying the absolute duration of the terminal link over conditions while maintaining a 2:1 ratio of terminal-link duration. He found that preference for the shorter terminal link was more extreme than expected. Thus, the data did not support the matching law. MacEwen concluded that the matching relation does not extend beyond the range of VI schedule durations used by Herrnstein (1961, 1964b). This type of result has become known as the terminal-link effect, where preference becomes stronger as the terminal-link duration increases.

Similarly, Williams and Fantino (1978) arranged a concurrent-chains schedule with a 2:1 ratio of reinforcement delay between alternatives. If the matching law accurately predicts the effect of relative immediacy, then there should be a 2:1 ratio of responses between these alternatives that is unaffected by the absolute value of delay.

Despite this constant ratio, preference was most extreme in conditions with the longest absolute delay. Thus, preference increased with increases in absolute delay, which is another example of the terminal-link effect. These results prompted Williams and Fantino to re-analyse Chung and Herrnstein's (1967) data using the generalised matching law. They reported that preference was also affected by absolute delay in Chung and Herrnstein's original experiment. Thus, according to Williams and Fantino, originally the matching relation was not actually supported.

Gentry and Marr (1980) also investigated inconsistencies in a matching-law account of preference for immediacy of reinforcement. They used a 4:1 ratio of reinforcement delay. As above, if relative immediacy is the primary determiner of choice then relative frequency of responses should match the 4:1 ratio. They found a pattern of undermatching, where relative response rate fell below that expected by the matching law, and they found an effect of absolute delay (higher response rate with shorter absolute delay). Clearly, *relative* immediacy is not the only determiner of choice. Thus, Gentry and Marr concluded that both relative and absolute delays affect choice.

Other researchers, however, have found no effect on preference of longer absolute delay (i.e., McDevitt & Williams, 2001). Thus, sensitivity to relative delay may not necessarily change with longer absolute delay (terminal-link duration) as previous studies have found.

In summary, research into concurrent chains and immediacy of reinforcement has shown that the duration of both the initial and terminal links can affect preference

and sensitivity to relative reinforcement. MacEwen (1972) found evidence to support the terminal-link effect, where greater sensitivity and stronger preference were found for the short terminal link when longer absolute terminal-link durations were scheduled. The matching law assumes that only relative values of reinforcement (delay in this case) affect preference. However, a change in preference occurred even though relative delay to reinforcement remained equal while absolute delay varied across conditions. Similarly, Williams and Fantino (1978) reported that sensitivity to relative delay to reinforcement increased with increases in absolute delay: preference for the shorter delay increased as absolute delay increased. Logue and Chavarro (1987) also showed increased preference for the shorter delay as absolute but not relative delay increased. Thus, it appears that sensitivity to terminal-link delay is a function of both relative and absolute terminal-link schedules. Taken together, these studies questioned the use of the generalised matching law as a complete model of preference in concurrent chains.

Overall, the consensus is that *both* relative and absolute delay to reinforcement influence preference. However, it is the magnitude of that preference that changes, not the preference *per se*: the reported data have all shown preference for the alternative offering the shortest delay to reinforcement. It is the degree of that preference that changes with manipulation of absolute delay. Thus, delay to reinforcement remains an important determiner of choice.

1.6.1: Concurrent chains and mathematical models of choice

In concurrent chains, relative initial-link responding is assumed to be a measure of preference for the terminal-link schedule and a measure of the value of terminal-link stimuli as conditioned reinforcers (Herrnstein, 1964; Fantino, 1977). Even though the matching law was not developed for application to concurrent chains, its success in describing concurrent performance inevitably led to its application to concurrent chains, as discussed above (Davison, 1983).

Demonstrations of the initial-link effect (Davison, 1983; Fantino, 1969) and the terminal-link effect (Grace & Bragason, 2004; MacEwen, 1972) have questioned application of the matching law to choice in concurrent chains. Mathematical models of choice have since developed in attempt to better describe and predict preference in concurrent chains. The first was Fantino's Delay Reduction Hypothesis (DRH; Fantino, 1969; Squires & Fantino, 1971), which provided a conditioned-reinforcement perspective on choice. Fantino and colleagues developed a model that was better suited to concurrent chains, as it attempted to account for both temporal context and terminal-link stimuli. Fantino (1969) reported that the DRH provided a good description of concurrent-chains data with both equal and unequal initial- and terminal-link durations. As Fantino pointed out, preference is not as simply determined as the matching law presumes.

The combined success of the DRH and the issues raised by the numerous aforementioned studies (i.e., Davison, 1983, 1987; Fantino & Davison, 1983) create a problem for a generalised-matching account of concurrent chains. However, if the

relationship between initial- and terminal-link durations and sensitivity to terminal links can be specified, then the matching law will continue to gain support (Davison, 1987; Grace, 1994). A more recent generalisation of the matching law attempted to solve the problems raised by Davison (1983) and others.

Grace (1994) developed the Contextual Choice Model (CCM) which appears able to account for choice in concurrent chains. A very important feature of CCM is the simple but novel extension of the matching law, where the temporal context (i.e., initial- and terminal-link durations) of the concurrent-chains procedure is assumed to influence sensitivity to relative reinforcement. Grace applied this model to data from a number of archival studies and found that on average 90.5% of the variance in initial link response rate was accounted for. Grace (1996) then demonstrated that CCM could be applied to the concurrent-chains procedure where delays were variable and to responding in another procedure (the adjusting delay procedure; Mazur, 1984), with the same high level of variance accounted for. Thus, not only has Grace continued the support for the generalised matching law, but he has developed a model that can be applied to data from many procedures. This is an extremely valuable contribution to the quantitative analysis of behaviour. DRH and CCM will be discussed in greater detail in sections to come.

From here we shall return to other dimensions of reinforcement that are determiners of choice: magnitude and probability of reinforcement will continue to be discussed in the context of the matching law.

1.7: Magnitude of reinforcement as a determiner of choice

Although a great deal of research has been conducted on rate of reinforcement, relatively few studies have investigated the effects of reinforcer magnitude as a determiner of choice (Landon, Davison & Elliffe, 2003). Moreover, results are inconsistent and ambiguous in those studies that have investigated reinforcer magnitude (Landon et al., 2003). The following studies have examined magnitude of reinforcement using either concurrent schedules or concurrent chains.

Catania (1963) varied reinforcer duration systematically across four conditions using both a single VI schedule and concurrent VI schedules. He found no effect on behaviour of reinforcer magnitude in the single VI schedule, but in the concurrent VI schedule conditions response rate was a linear function of reinforcer magnitude.

Schneider (1973) reported that preference for an alternative decreased as the reinforcers associated with that alternative became larger but less frequent. Specifically, responding was maintained at a higher rate with smaller, more frequent, reinforcers than with larger, less frequent, reinforcers. Thus, the ratio of responses was inversely related to the ratio of pellets per reinforcement. Although Schneider confirmed relative reinforcer magnitude as a determiner of choice, he found that when frequency and size of reinforcement were varied, preference was not adequately described by the matching law. Furthermore, undermatching was found when reinforcer magnitude was held constant and rate was varied, and became even more apparent when reinforcer rate was held constant as magnitude varied (by offering unequal amounts of reinforcement). In addition, when reinforcer rate and magnitude

were varied inversely so that their product was constant, preference shifted in the direction of change in reinforcer rate. Thus, reinforcer rate exerted more control over preference than reinforcer magnitude did. Schneider concluded that a combination of reinforcer rate and magnitude jointly determined choice. By manipulating more than one aspect of reinforcement simultaneously, as Schneider did, relative sensitivity of behaviour to various dimensions of reinforcement can be assessed. Other researchers have also found different sensitivity of behaviour to relative changes in different aspects of reinforcement.

Todorov (1973) also found disparity in the sensitivity of subjects to relative changes in reinforcer rate and magnitude. Todorov used a concurrent VI VI design where three components were presented during a session. Within each component, the reinforcer rate was held constant while the reinforcer duration varied (from 2 to 8 s). However, each component had a different absolute reinforcer rate (from VI 36 to 90 s). Thus, he was assessing the interaction of the effects of reinforcer frequency and magnitude on concurrent VI performance. Todorov used two measures of preference, relative response rate and relative time allocation, and assessed the effect on those measures of relative total access to reinforcement (the product of reinforcer rate and duration) and relative reinforcement value. Reinforcer value was defined as the product of reinforcer rate and magnitude, each raised to a power (sensitivity). In Equation 1.6, R is response rate, r is reinforcer rate, d is reinforcer duration (or magnitude), the subscripts 1 and 2 are the alternatives, and the superscripts a and b are the sensitivity values of each rate and duration respectively.

$$\frac{R_1}{R_1 + R_2} = \frac{r_1^a \cdot d_1^b}{\left(r_1^a \cdot d_1^b\right) + \left(r_2^a \cdot d_2^b\right)} \tag{1.6}$$

Todorov found that choice did not match relative total access to reinforcement as previously reported (Neuringer, 1967; Ten Eyck, 1970). Although dimensions of reinforcement had a combined effect on behaviour, he found that reinforcer rate had a much more powerful effect on choice behaviour than reinforcer magnitude did. Specifically, sensitivity to reinforcer duration was always less than sensitivity to reinforcer frequency (i.e., Equation 1.6 fitted the data with $b < a$). Thus, like Schneider, Todorov concluded that rate and magnitude are not interchangeable as one had a greater effect on behaviour than the other did.

Keller and Gollub (1977) further investigated the issue regarding relative total access to reinforcement as a determiner of choice. Using a procedure where both reinforcer frequency and duration varied, they found that when varied together neither had as great an effect on response distribution as they did when varied separately. Specifically, they found a pattern of undermatching for both reinforcer frequency and magnitude. Furthermore, the obtained response distributions did not match to relative total access to reinforcement as hypothesised. However, in a second experiment with longer schedule duration, they found that response distribution did indeed match to relative total access. They concluded that schedule duration might play an important role in determining the level of preference and matching.

Logue and Chavarro (1987) also found data inconsistent with matching: that absolute reinforcer amounts affect the ratio of responses. They held the ratio of reinforcement magnitude constant at 3:1 and varied the absolute duration of

reinforcement. At larger absolute magnitudes of reinforcement, as expected preference for the alternative offering the larger reinforcer was between three and four times greater than that for the smaller reinforcer. However, they found an orderly decrease in preference for the larger reinforcer as absolute amount of reinforcement increased (and relative amount remained constant). Although this result was not predicted by the matching law, it still confirms reinforcer magnitude as a determiner of choice.

More recently, McLean and Blampied (2001) found that sensitivity to variations in relative reinforcer rate was constant when absolute reinforcer magnitude was varied. In the first part of their experiment, sensitivity to relative reinforcer rate did not vary systematically with equal-sized reinforcer magnitudes. However, in the second part with unequal-sized reinforcers, sensitivity values were lower than in the first part. Thus, there was a possible effect of relative reinforcer magnitude on sensitivity to relative reinforcer rate. However, they were unable to draw a strong conclusion, as there was a great deal of between-subject variation. Thus, to investigate this finding further, they conducted a third part using both equal- and unequal-sized reinforcers. Sensitivity estimates with equal- or unequal-sized reinforcers did not differ systematically. Thus, the possible effect noted in the first part of the experiment was not replicated in the latter part. Overall, there was no evidence to support an interaction between relative reinforcer rate and relative magnitude, or to suggest a great difference between the sensitivity estimates for reinforcer frequency and magnitude.

Landon, Davison and Elliffe (2003) designed an experiment to investigate parametrically the effects of reinforcer magnitude in a standard concurrent switching procedure. Relative reinforcer magnitude was varied over five levels by changing the number of 1.2 s hopper presentations across conditions, while the reinforcer frequency was held constant. In all conditions, the sum (across the two alternatives) of the number of hopper presentations was always eight. They found that mean sensitivity to reinforcer magnitude when based on response allocation was .76. The sensitivity values were higher when time allocation was used as the dependent variable, with a mean of 1.15. Although these results were higher than previously reported sensitivity values, they were consistently lower than those they found for reinforcer frequency with the same subjects (Landon, Davison & Elliffe, 2002). Their results were well described by the generalised matching law, as log response ratios were a linear function of log reinforcer-magnitude ratios. This is inconsistent with results from Davison and Hogsden (1984) who found a non-linear relation between log response ratios and log reinforcer-magnitude ratios. Landon et al. suggest that a procedural difference could be the reason for this inconsistency. Davison and Hogsden held reinforcer duration constant at one alternative and varied it at the other, thus changing the overall reinforcer duration across conditions; whereas Landon et al. held total reinforcer duration constant (at eight hopper presentations or 9.6 s) across conditions. Data from this study support the general finding that both reinforcer frequency and amount control behaviour; however, the degree of that control is greater by reinforcer frequency than by reinforcer magnitude.

Several studies have varied relative magnitude of reinforcement in concurrent chains schedules – having subjects choose between different magnitudes of

reinforcement that are equally delayed. Shull, Mellon and Sharp (1990) manipulated the number of food deliveries after various delays rather than frequencies. They found a preference for the terminal link that offered the highest sum of immediacies (i.e., the sum of the reciprocals of delays to reinforcers after the choice). Thus, each food delivery affected choice, but neither the total number of deliveries nor the total amount of food received were sole determiners of choice.

Fantino, Squires, Delbrück and Peterson (1972) varied reinforcer magnitude across three different absolute rates of reinforcement. They found a systematic reduction in preference (from near exclusive preference to moderate preference) as the absolute reinforcement rate decreased. They reported, however, that choice proportions matched neither scheduled nor observed proportion of reinforcer time (number of reinforcers multiplied by reinforcer duration). This is inconsistent with previous research that found matching to relative reinforcer magnitude (i.e., Brownstein, 1971; Catania, 1963).

To some extent, research into reinforcer magnitude has been mixed. One consistent conclusion is that reinforcer magnitude is indeed an important determiner of choice. What has been less clear is the level to which reinforcer magnitude affects choice in comparison with other dimensions of reinforcement. Some findings suggest that magnitude has a less potent effect on choice behaviour than does reinforcer rate (i.e., Todorov, 1973). On the other hand, some report no difference between the sensitivity of behaviour to either reinforcer rate or magnitude (i.e., McLean & Blampied, 2001).

1.8: Summary of determiners of choice

The Matching Law has been reported to predict and describe the effects on behaviour of various dimensions of reinforcement. These include reinforcement rate, delay and magnitude. Specifically, the matching law states that relative responding matches relative reinforcement. Procedures used to investigate predictions of the matching law (i.e., concurrent schedules) often employ a change-over delay (COD) to reduce switching between alternatives. A COD of a minimal duration enhances control of behaviour by relative reinforcement.

The matching law was then applied to choice in a new procedure, the concurrent-chains procedure (Herrnstein, 1964). Initially, delay to reinforcement (terminal-link duration) was also found to produce matching (i.e., Chung & Herrnstein, 1967). However, subsequent researchers noted that the absolute duration of the terminal link affects preference. For example, MacEwen (1972) reported that preference for the shorter terminal link increased as the absolute terminal-link duration increased (the "terminal-link effect"). Another issue regarding the application of the matching law to choice in concurrent chains arose when Fantino reported that preference for the shorter delay decreased as the duration of the initial links increased (the "initial-link effect"; Fantino, 1969). Once again, the generality of the matching law has been tested and challenged to adequately describe and predict the influence of various dimensions of reinforcement on choice.

Relative reinforcement magnitude has also been found to produce matching of relative responding: where preference favours the alternative with the larger

reinforcer. The matching law is a statement about relative reinforcement, thus it is assumed that absolute values of reinforcement do not affect choice. However, several studies (e.g., Logue & Chavarro, 1987) have reported violations of the relativity assumption of the concatenated matching law: that the absolute magnitude of reinforcement influences preference as does the relative magnitude of reinforcement. Specifically, preference for the larger reinforcer decreases with absolute amount of reinforcement increases. Others (e.g., Davison, 1988) have reported violations of the independence assumption of the concatenated matching law. Davison reported an interaction between relative reinforcer rate and magnitude, thus concluding that they do not have independent effects on behaviour.

Thus far, rate, immediacy and magnitude of reinforcement have been described by the matching law as determiners of choice. The degree of control established by these dimensions of reinforcement has varied, but overall the matching law has successfully described preference between alternatives offering different rates, immediacies and magnitudes of reinforcement. One dimension of reinforcement that has received relatively little attention is probability of reinforcement. We shall turn to that now.

1.9: Probability of reinforcement as a determiner of choice

Probability of reinforcement has received relatively less attention in the literature than delay as a determiner of choice. However, much of what has been done has used chained schedules similar to the concurrent chains procedure used in the present research. In a typical 'chained' procedure, subjects are required to

complete a schedule (i.e., FR 15) before the outcome phase begins, which is usually a fixed-time (FT) schedule. There is only one alternative and reinforcement is delivered probabilistically.

Branch (1977) using a chained procedure with probabilistic reinforcement, found that frequency of chain completion by the subject decreased as the percentage of reinforced trials decreased. One of the most commonly reported findings in the early literature on reinforcer probability is an increase in response rate following a decrease in percentage of reinforced trials. Specifically, response rate is higher in conditions where in some trials reinforcement is omitted (i.e., $p(R) < 1$). This is referred to as the "omission effect" (e.g., Branch, 1977; Staddon & Innis, 1969).

Zeiler (1972) varied the proportion of trials ending with reinforcement. He found an increase in response rate when the percentage of reinforced trials decreased from 100 to 90%. Thereafter, response rate remained stable or gradually declined until the probability of reinforcement was equal to or less than 30%, when response rate dropped dramatically. Overall, the highest response rate was observed in the 90% reinforcement condition. Zeiler's results replicate those of Staddon and Innis (1969) and Zimmerman (1971), who also found that response rate was higher in those trials where the probability of reinforcement was less than one.

The concurrent-chains procedure is now commonly used to assess the effect on preference of relative and absolute reinforcer probability, and how that preference depends on temporal context. Spetch and Dunn (1987) investigated probabilistic reinforcement while varying the duration of initial- and terminal-link schedules. The

eventual outcome of each trial was never differentially signalled by terminal-link stimuli (called an "unsignalled" procedure). They held the relative percentage of reinforced trials constant while the overall absolute percentage of reinforcement was varied across conditions. They found a strong, consistent preference for the more reliable alternative, which did not vary with absolute percentage of reinforcement. This is consistent with the relativity assumption of the matching law. Spetch and Dunn also found that preference for the more reliable alternative was more extreme with shorter initial links and longer terminal links. This replicates the initial-link and terminal-link effects described earlier. In a further experiment, they found the expected preference for the shorter terminal link was not systematically affected by changes in absolute percentage of reinforced trials. In summary, these experiments support application of the generalised matching law to choice between alternatives differing in reinforcer probability.

With research into the effects of both relative and absolute probability of reinforcement well underway, interest (although somewhat limited to date) turned to the interactions between probability and other variables, such as magnitude. Young (1981) investigated the effects of varying magnitude of reinforcement on one alternative, while varying the probability of reinforcement on the other, in a discrete-trial choice procedure. He offered pigeons the choice between an uncertain alternative (10 or zero food pellets at probability of .5) and a certain but variable alternative (the number of food pellets ranged from one to 10, with a probability of one). Overall, he found that as the number of food pellets presented on the certain alternative increased, choice of the uncertain alternative decreased.

One measure of reinforcement Young (1981) used was the 'expected value'. He calculated the expected value of each alternative by multiplying the probability by the magnitude of reinforcement. In Young's experiment, the two alternatives have equal expected value when five food pellets were presented on the certain alternative. When there is equal expected value, we might expect subjects to be indifferent between the two alternatives. However, Young found that when the certain alternative delivered five pellets (the expected point of indifference) the average choice proportion favoured the uncertain alternative. Thus, he found a preference for the uncertain alternative even though each alternative offered the same expected value of reinforcement. This result is an example of risk-prone choice, which is inconsistent with results from Hamm and Shettleworth (1987) who reported risk-averse behaviour, i.e., a preference for the fixed magnitude of reinforcement.

In general, the graded change in preference obtained (reduced preference for the uncertain alternative as the magnitude of the certain reinforcer increased) was inconsistent with the reinforcement-maximization principle (Young, 1981). Furthermore, it was also problematic for the matching law, as subjects clearly did not match to relative expected value of reinforcement. The uncertain alternative was preferred to a greater extent than expected. Young suggested that there is a weighted preference for reinforcer magnitude. Small magnitudes are valued more highly than expected and larger magnitudes are valued less than expected. Alternatively, Young's data could represent a preference for uncertainty. This possibility is supported by research with rats as subjects (i.e., Levanthal, Morrel, Morgan & Perkins, 1959).

Research into probability of reinforcement has yielded some interesting results. For example, changes in probability of reinforcement affects preference – Spetch and Dunn (1987) found a strong preference for the more reliable alternative, which did not vary with absolute percentage of reinforcement. However, this preference was affected by the absolute durations of the initial- and terminal-links; i.e., the initial- and terminal-link effects. In addition, probability combines with other reinforcement variables, such as magnitude, to have interesting effects on preference. This research indicates that probability of reinforcement is a determiner of choice and it should therefore be considered as an important dimension of reinforcement in mathematical models of choice.

Much of the research conducted on reinforcer probability has used the concurrent-chains procedure. So returning to concurrent chains, a variation on this procedure uses *signalled* probabilistic scheduling of reinforcement in the terminal link, where stimuli presented in the terminal links signal which of the two possible outcomes (i.e., reinforcement or no reinforcement) will occur at the end of the delay. Designing procedures in this way permits assessment of the effects on preference of signals for mixed (or variable) terminal-link outcomes. This leads us into discussion of signalled reinforcement and its effects on preference.

1.10: Signalled reinforcement

We are able to study a choice between reliable ($p(R) = 1$) and unreliable ($p(R) < 1$) reinforcement by manipulating the percentage of trials ending in reinforcement. This means that some trials may end in reinforcement and others may not. In addition

to manipulating the percentage of reinforcement, stimuli may be used to signal the outcome in that terminal link. These stimuli may or may not be correlated with the eventual reinforcement outcome of the trial. Specifically, in signalled procedures (also known as correlated or multiple procedures) the terminal-link stimuli differentially signal the eventual outcome (either reinforcement or blackout). In unsignalled procedures (also known as uncorrelated or mixed procedures) the terminal-link stimuli do not differentially signal the eventual reinforcement outcome.

As previously discussed, preference is usually controlled by the relative reinforcement parameters (i.e., Baum, 1974; Herrnstein, 1961). The typical result in an unsignalled percentage-reinforcement procedure is a strong preference for the reliable or rich alternative. Preference can, however, be affected by differentially signalling reinforcement outcomes. Specifically, in signalled procedures, preference for the reliable alternative can be greatly reduced by signalling the outcomes on the unreliable or poor alternative (i.e., Dunn & Spetch, 1990; Mazur, 1991). Firstly, we will discuss the preference for signalled alternatives and then turn to the signalling effect.

1.10.1: Preference for signalled alternatives

A preference for signalled alternatives has often been reported. For example, Prokasy (1956) reported that rats preferred to run to a goal box with a signalled delay rather than one with no signal. Bower, McLean and Meacham (1966) and Hendry (1969) found similar results using pigeons as subjects. They found that when both

multiple (signalled) and mixed (unsignalled) alternatives were offered concurrently, subjects preferred the signalled option almost exclusively.

Green and Rachlin (1977) suggested that this preference for signalled alternatives was to do with the amount of information provided by the stimuli. They offered pigeons the choice between an *informative* alternative (where terminal-link stimuli differentially signalled the eventual outcome) and an *uninformative* alternative (where terminal-link stimuli were uncorrelated with the eventual outcome). Each alternative delivered probabilistic reinforcement. All birds preferred the informative alternative. This result was maintained even in the condition with equal probability of reinforcement on both alternatives (i.e., P(R) = .5 on each). They suggested that the "information" provided by the stimuli should be interpreted in light of the context in which they were presented: the information relates to both reinforcement and non-reinforcement outcomes. Bower et al. (1966) also suggested that pigeons preferred to get information regarding the outcome in advance. These studies strongly support the notion of a preference for signalled, informative alternatives over unsignalled, uninformative alternatives. On the other hand, however, some researchers have found preference for the unsignalled terminal link (e.g., Menlove and Masterton, 1980).

In related research, Alsop and Davison (1986) presented subjects with a choice in the initial link that led to one of two equal-duration terminal links, which were either multiple (signalled) or mixed (unsignalled). They found that subjects preferred the multiple over the mixed terminal link when the initial link was shorter. Conversely when the initial link was longer, they found a preference for the mixed over the multiple alternative. However in a second experiment, when the initial links

were of equal duration, they found no difference in preference for either terminal link, as the absolute terminal-link duration increased. Thus, the reported preference for signalled alternatives may not be entirely reliable.

Despite some inconsistencies, a great deal of interest has been paid to the effects of these signals. Why would signals in the terminal link have such an impact on preference? And by what mechanisms do they influence preference? These are examples of the questions raised by the signalling research. The most impressive demonstration of the impact of signals of reinforcement is the signalling effect.

1.11: The Signalling Effect

Possibly related to the preference for signalled alternatives is the signalling effect. The signalling effect is often investigated using the concurrent-chains procedure, with unequal reinforcement rates (arranged by manipulating the percentage of reinforced trials). Kendall (1974) investigated preference in a signalled concurrent-chains procedure, using percentage reinforcement on each alternative (100 versus 50%). In some conditions in the unreliable alternative, stimuli were presented that were correlated with the outcome. Specifically, one stimulus was correlated with reinforcement and another stimulus was correlated with extinction. Kendall hypothesised that the stimulus correlated with reinforcement on the unreliable alternative would acquire additional conditioned reinforcing strength because of the association with reinforcement. This hypothesis has continued to be tested.

Kendall (1974) found the expected preference for the more reliable terminal link in unsignalled conditions. Interestingly, however, he found a preference for the uncertain alternative in signalled conditions where the terminal-link stimuli differentially signalled the eventual outcome. This result is called the "signalling effect", and has also been reported in other choice procedures (e.g., Mazur, 1991; 1993).

Kendall's results were challenged by Fantino, Dunn and Meck (1979) because of an unusual feature in his procedure. Specifically, Kendall used unlit response keys in the initial link. Fantino et al. (1979) used illuminated keys in the initial links in an otherwise similar procedure, and found no consistent preference for the uncertain alternative. However, Kendall (1985) also replicated his previous results using illuminated response keys, and again found a preference for the unreliable alternative in the signalled procedure. He also reported limitations to this preference. Specifically, this preference was only apparent when the initial-link schedules were short and the terminal-link schedules long (Kendall, 1985).

More recent research has provided support for Kendall's (1974, 1985) findings. In a comprehensive paper, Dunn and Spetch (1990) systematically varied the duration of the initial and terminal links, the percentage of reinforced trials and signalling in the terminal links. They found that when the outcomes on the unreliable alternative are differentially signalled, the extent of preference for the more reliable alternative is an increasing function of *both* initial- and terminal-link durations. Moreover, that preference for the reliable alternative was highest in unsignalled conditions with short initial links. The results of these experiments show that

preference is determined by initial-link schedules, terminal-link durations, and stimulus conditions in the terminal link. These experiments will be discussed in more detail in the General Discussion.

Spetch, Belke, Barnet, Dunn and Pierce (1990) also investigated the signalling effect using a probabilistic concurrent-chains procedure. Terminal-link outcomes on the unreliable alternative were either signalled or unsignalled. They varied the absolute terminal-link duration across conditions, while the initial-link schedule was always FR 1. They reported a substantially reduced preference for the reliable alternative in the signalled relative to the unsignalled conditions. Furthermore, choice of the unreliable alternative increased as the terminal-link duration increased. These results replicated the signalling effect, reported by Kendall (1975, 1985) and Dunn and Spetch (1990).

Various procedures other than concurrent chains have been used to study the effects on choice of signalling reinforcement. One such procedure is Mazur's adjusting-delay procedure (e.g., Mazur, 1984). In this procedure, pigeons are offered the choice between a standard delay and an adjusting delay. These delays are titrated until an indifference point is obtained: the point at which each delay is chosen equally often. If the adjusting delay is longer at that point, then preference for that alternative is inferred; conversely, if the fixed delay is longer at that point, then preference for that alternative is inferred.

Mazur (1993) trained pigeons to choose between two alternatives. Choice of the probabilistic (uncertain) alternative led either to food or no food, after a 5 s delay.

Both outcomes (food or no food) were signalled by a red key light, thus the outcomes were not differentially signalled. Alternatively, pecks to the certain alternative were always followed by reinforcement, which was signalled by a green key light. He found that when the outcomes were signalled in this way, the final adjusted delay was 17 s. This meant that pigeons would choose each of the two alternatives equally often when the delay to reinforcement on the certain alternative was 17 s and the delay on the uncertain alternative was 5 s. Given what we know about delayed and probabilistic reinforcement, this result seems reasonable as the subjects obtained more reinforcement on the certain alternative and were therefore more likely to tolerate a longer delay.

In a second condition, the two possible outcomes (reinforcement and no reinforcement) on the uncertain alternative were now differentially signalled. Specifically, trials ending in reinforcement were signalled by a red key light (as above); however, in trials where no reinforcement was scheduled the houselight was illuminated immediately after the choice was made. Mazur (1993) found that when the two possible outcomes on the probabilistic side were signalled in this way, the final adjusted delay on the certain alternative decreased to approximately 7 s. This meant that the pigeons were more or less indifferent between these two alternatives as the delays were 5 and 7 s on the uncertain and certain sides, respectively. Thus, pigeons would choose the two alternatives about equally often, even though they obtained substantially less food from one alternative.

The results from this experiment support Mazur's (1993) hypothesis that the value of a probabilistic reinforcer is determined by the time spent in the presence of

the stimulus associated with that reinforcer, and that the specific delay to and probability of reinforcement are less important or valuable to the subject, in determining choice, than that stimulus is. Mazur's work is remarkable because it shows that pigeons will choose a less optimal alternative, given certain circumstances. Specifically, when each alternative has a unique signal associated with its reinforcement (and the delay to that reinforcement) pigeons may be indifferent between the two alternatives even if one alternative delivers much less food. Mazur presented results that support the view that conditioned reinforcers (i.e., the signals) increase the value of the alternative with differentially signalled outcomes, beyond the value it would have without these signals. This improvement in value in a probabilistic alternative may offset the diminished value it had because of the lower probability of reinforcement, thus, making the two alternatives with unequal reinforcement, nearly equal. It appears that the strength or value of the signal is determined by the delay to reinforcement (that is, time spent in presence of this conditioned reinforcer) and by how informative the signal is to the subject (Fantino, 1977; Mazur, 1991, 1993; McDevitt, Spetch & Dunn, 1997). The work by Mazur takes a slightly different approach than the other studies; however the results are consistent with the signalling effect reported by Kendall and by Dunn and Spetch.

In summary, the above studies have indicated a reduced preference for the reliable alternative when outcomes in the unreliable (probabilistic) alternative are differentially signalled. Is this phenomenon specific to probability? Does it occur when other dimensions of reinforcement are signalled, such as reinforcer magnitude? Consider the situation where two possible outcomes in one terminal link are signalled, i.e., different magnitudes of reinforcement: would the signalling effect occur? If not,

the conclusion might be that the signalling effect is a result of probabilistic scheduling of reinforcement. However, if the signalling effect does occur with other dimensions of reinforcement then it would appear that signalling the eventual outcome influences the global value of the terminal link, thus affecting preference. These effects could be modelled using Grace's (1996) Contextual Choice Model. I will return to the application of CCM to the signalling effect when discussing the present experiments. For now, I would like to return to the topic of determiners of choice.

We have already discussed multiple determiners of choice, including reinforcer rate, delay, magnitude and probability. We have also discussed the effects on preference of signalling these reinforcement outcomes. There is another aspect of reinforcement that deserves some attention: variability of reinforcement. In the literature thus far, variability has not been considered a determiner of choice *per se*, in that it has not been included in any mathematical model of choice as have the previously mentioned dimensions of reinforcement. This non-inclusion should not preclude variability being considered as an important determiner of choice.

Firstly, I will briefly outline one justification for its inclusion, and then move on to the literature on fixed versus variable dimensions of reinforcement. Upon considering the 'make up' of probabilistic scheduling of reinforcement, it occurs to me that this schedule is actually constructed of mixed (variable) magnitudes. Consider the experimental situation offering a p(R) = .5. This might reasonably be viewed as a mixed-magnitude situation, with reinforcers of 3 or 0-s. Thus, there is a degree of variability inherent in probabilistic scheduling. The magnitude-variability can be altered by changing the absolute percentage of reinforcement offered by each

alternative, or by changing the magnitudes of reinforcement. Overall, variability of reinforcement might be an important determiner of choice in these procedures, which has thus far been overlooked as an explicit influence.

1.12: Variability of reinforcement as a determiner of choice

The study of preference between fixed and variable reinforcement outcomes has been ongoing (see discussion in Mazur, 1991). One common finding is that subjects prefer variable over fixed delays to reinforcement. Specifically, it has been found that given the choice between an alternative offering reinforcement after a fixed delay and one offering reinforcement after a variable delay (the arithmetic average of which equals the fixed delay experienced at the other alternative), pigeons tend to choose the variable alternative (i.e., Herrnstein, 1964; Mazur, 1984). Numerous studies have since reported similar results with a larger range of VI schedules (i.e., Davison, 1969; Killeen, 1968); ratio schedules (i.e., Fantino, 1967; Navarick & Fantino, 1972) and fixed (FT) and variable (VT) delays (Cicerone, 1976).

Davison (1969) offered pigeons the choice between two alternatives in a concurrent-chains procedure. The terminal-link schedule on one alternative was a fixed-interval schedule, which varied from FI 10 s to FI 30 s across conditions. The other terminal link delivered reinforcement after a variable delay. Specifically, the terminal-link schedule was a two-value mixed-interval (MI) schedule, MI 15 s MI 45 s. Davison reported that when the arithmetic mean delays on the two alternatives were equal (i.e., when FI 30 s was in effect on the fixed alternative) subjects strongly preferred the variable terminal link.

Given this preference for variable delays, interest turned to finding indifference points between fixed and variable delays. Specifically, addressing questions such as when will fixed delays be equally preferred to a variable delay? Mazur's adjusting delay procedure (i.e., Mazur, 1984) has been used to address this issue. As discussed previously, in this procedure, pigeons are offered the choice between a standard delay and an adjusting delay. These delays are titrated until an indifference point is obtained. If the adjusting delay is longer than the standard delay at that point, then preference for variability is inferred; conversely, if the fixed delay is longer at that point, then preference for fixedness is inferred. Results from several of Mazur's studies (i.e., Mazur, 1984) support previous findings of a preference for mixed over fixed delays.

In summary, results of several studies have shown a consistent preference for variable over fixed delays. This has been interpreted as a preference for variability. However, others (i.e., Fantino, 1969; Killeen, 1968) have suggested that it is not about variability *per se*; rather this preference is about the value of the delay and conditioned reinforcers associated with such a delay. The generality of this statement has been tested by varying other dimensions of reinforcement (i.e., magnitude) rather than delay to reinforcement.

Essock and Reese (1974) trained pigeons on a multiple schedule that delivered a fixed or variable amount of food, with each schedule delivering an equal mean amount of food. They found that response rate was greater in the variable component. This finding was supported by similar results from a second condition using concurrent VI VI scheduling. They concluded that the preference for variability was

not specific to delay, but could be generalised to reinforcer amount. However, it is possible that the response rate generated by each of the concurrent schedules influenced this result; the relative response rate may not actually reflect a preference for variability rather it may be a result of the subject receiving reinforcers after shorter, albeit variable, delays. Their data contrasted with earlier research by Staddon and Innis (1966) who found indifference between fixed and variable reinforcer magnitudes.

More recently, researchers have found that pigeons prefer fixed reinforcer magnitudes over variable ones (i.e., Hamm & Shettleworth, 1987; Menlove, Inden & Madden, 1979). Hamm and Shettleworth (1987) offered pigeons a choice between a fixed and a variable amount of food. In their first experiment, they used a concurrent VI VI schedule procedure, and in their second experiment they used a discrete-trial procedure. One alternative (fixed) always delivered two pellets of reinforcement and the other (variable) sometimes ended in four pellets of reinforcement and sometimes ended in none. Thus, the average amount of reinforcement was equal (two pellets) on both alternatives. They found a moderate preference for the fixed over the variable alternative. They attempted to magnify this preference by increasing the mean number of pellets on both alternatives and thus the variability of reinforcement. Therefore, these experiments enabled comparison of not only fixed versus variable reinforcement, but also the degree of variability. They found that preference for the fixed alternative increased as the degree of variability increased. Overall, the results of Hamm and Shettleworth's experiments suggest that pigeons prefer constant, fixed magnitudes of reinforcement, and that they find greater variability of reinforcement magnitude (relatively) aversive. Davison and Hogsden (1984) also investigated

variability of reinforcement. They manipulated the variability of reinforcement magnitude and probability using concurrent VI VI schedules.

Davison and Hogsden (1984) trained pigeons on concurrent VI schedules and analysed performance in terms of preference for fixed versus mixed reinforcer durations, available on the two alternatives. They conducted an extensive experiment involving five parts, each varying different combinations of schedule duration, reinforcer duration and variability of reinforcement, over a total of 34 conditions.

One alternative was designated the mixed alternative and the other designated the fixed alternative. The mixed alternative sometimes delivered a small reinforcer and sometimes delivered a large one. The probability of the smaller reinforcer varied across conditions. The fixed alternative always delivered the same medium-sized reinforcer. One aim of their experiment was to investigate whether the generalised matching law could be extended to account for variability within schedules of reinforcement. Their extension is shown in Equation 1.7. Two possible reinforcement magnitudes (A_{L1} & A_{L2}) on the left alternative, delivered probabilistically at two rates (N_{L1} & N_{L2}); while the right alternative involves a single reinforcer duration (A_R) at the rate N_R. Equation 1.7 also includes parameters for sensitivity to reinforcer-rate ratios (a), sensitivity to reinforcer-duration ratios (d) and a bias parameter (c).

$$\frac{B_1}{B_2} = \frac{c\left(N_{L1} \cdot A_{L1}{}^{d} + N_{L2} \cdot A_{L2}{}^{d}\right)^{a}}{N_R{}^{a} \cdot A_R{}^{ad}} \tag{1.7}$$

In Part 1, the probability of the smaller reinforcer in the mixed alternative varied over conditions: sometimes the small reinforcer was more likely and at other times the larger reinforcer was more likely. Part 3 was a replication of Part 1 with larger magnitudes of reinforcement. Results from Parts 1 and 3 showed that as the probability of the smaller reward increased, relative response rate to the mixed alternative decreased.

In Part 2, the mixed alternative sometimes delivered a reinforcer that was the same as the fixed alternative and sometimes delivered one that was larger or smaller. Therefore, sometimes the reinforcer delivered from the mixed alternative was larger than that delivered from the fixed alternative. The data showed that as the duration of the larger reinforcer increased, relative response allocation to the mixed alternative also increased.

Overall data from these three parts were poorly described by both the generalised matching law and their extension of it (Equation 1.7). Thus, Part 4 was designed to obtain precise measures of sensitivity to reinforcer-rate ratios (a) to ensure that subjects were sensitive to their manipulations. They varied relative reinforcer frequency and held reinforcer magnitude ratios constant. Analysis indicated that response allocation in Part 4 was within the normal range, an average sensitivity estimate (a) of .87 was obtained. The data were described accurately by the generalised matching law. Part 5 was designed to obtain precise measures of sensitivity to reinforcer-duration ratios (d) by varying relative reinforcer magnitude while holding reinforcer-rate ratios constant. The data from Part 5 showed a non-linear increase in response ratio as the reinforcer duration ratio increased. As it was

non-linear, the generalised matching law could not be used to accurately model the data thus an estimate of *d* was not obtained (Davison & Hogsden, 1984). Davison and Hogsden concluded that there may have been an interaction between reinforcer rate and duration that these models are not accounting for. In addition, they stated that the concatenated generalised matching law was not able to account for the effects of variable reinforcer duration.

An additional feature of the results that Davison and Hogsden were unable to explain was the consistent bias, across subjects and conditions, towards the fixed alternative. It is possible that this bias was an example of the reported preference for fixed over mixed magnitudes of reinforcement. This is a possibility that was not considered by the authors.

Variability has not only been investigated in the operant literature, but also in the behavioural ecology and foraging literature. Many procedural factors differ between these two bodies of research; for example the experimental subjects differ – within operant psychology pigeons and rats are often used (Herrnstein, 1964; Levanthal, Morrell, Morgan & Perkins, 1959), whereas in behavioural ecology, small sparrows and juncos are often used (Caraco, 1982). A further difference relates to the dimension of the outcome; for example, in operant psychology delay to reinforcement is often manipulated (Herrnstein, 1964), whereas amount of reinforcement is often varied in behavioural ecology (Caraco, Martindale & Whittam, 1980). Research from operant psychology tends to report preference for variable outcomes, whereas behavioural ecology reports that preference differs depending on the energy budget. That is, they conclude that the function of foraging on unpredictable food sources

differs depending on physiological states, e.g., hunger and thirst. The models that behavioural ecology has used to predict and describe results tend to be based on forms of reward-rate maximisation (Bateson & Kacelnik, 1995). Behavioural ecology has also applied Weber's Law of memory and Scalar Expectancy Theory (theoretical framework for time; Bateson & Kacelnik, 1995; Gibbon, 1977) to memory for reinforcement amount, rather than delay. However, in operant psychology, theories of conditioned reinforcement are more often used to predict and describe results relating to choice. The present research, being based in operant psychology, also relates results to models of conditioned reinforcement.

Returning specifically to variability of reinforcement – variability of reinforcer magnitude might be an important factor to consider in the studies on the signalling effect, which has been largely overlooked. Pigeons appear to prefer fixed magnitudes of reinforcement, and this preference may be reduced by signalling reinforcement outcomes. We will now turn to discussion on the present research.

1.13: The Present Research

The present research aims to further our knowledge with regards to the effects on preference of signalling primary reinforcement in the concurrent-chains procedure. A review of the literature has revealed a number of areas that require additional research to achieve this goal of a more complete knowledge base. One concerns the generality of the signalling effect: is it confined to percentage-reinforcement procedures, or does signalling other reinforcement variables (i.e., magnitude) have a similar effect on preference? Thus the current research begins with a simple experiment (Experiment 1, Part 1), which replicates the signalling effect using a percentage-reinforcement concurrent-chains procedure. Although a great deal of research has been conducted using percentage-reinforcement procedures, there are relatively few data available in the signalling literature about preference for other variables of reinforcement, such as magnitude. Thus, Experiment 1 Part 2, investigates the signalling effect in a similar procedure to Part 1, using certain reinforcers of differing magnitudes. The critical issue was whether signalling terminal-link outcomes has the same effect when magnitude of reinforcement is signalled rather than reinforcer probability.

Another issue to consider is the effect of signalling on the preference for fixed over variable magnitudes of reinforcement. Experiment 2 addresses this issue, by varying relative variability of reinforcer magnitude while holding all other parameters of reinforcement (e.g., relative expected magnitude) constant and equal across alternatives.

A third experiment (Experiment 3) addresses a related issue. Specifically, Experiment 3 asked whether a signalling effect would be obtained when relative variability of reinforcement was held constant as relative expected magnitude varied. In Experiment 3, a multiple concurrent-chains procedure was used, where two components were presented successively during a session.

Of notable absence in the literature on signalled reinforcement is a parametric data set on signalled relative reinforcer probability, immediacy and magnitude. This would permit assessment of the independence of reinforcement variables in parametric signalled procedures. Asking, does signalling relative probability of reinforcement affect sensitivity to the other variables of reinforcement? If so, this might suggest in interaction between reinforcer probability and the other variables of reinforcement. Thus, it is possible that the independence finding will fail under signalled conditions. Experiment 4 investigated the signalling effect while parametrically varying relative reinforcer probability and *immediacy*, and did so using a three-component concurrent-chains procedure.

Experiment 5 also investigated the signalling effect while parametrically varying relative reinforcer probability and *magnitude*, again using a three-component concurrent-chains procedure. The present research should provide the required information to develop a more complete literature on the signalling effect.

CHAPTER 2: EXPERIMENT 1

2.1: INTRODUCTION

The "signalling effect" refers to the finding that pigeons can be indifferent between two alternatives that differ substantially in terms of their reinforcement outcomes. Specifically, if one alternative offers a delay followed by a low probability of food and the other offers a delay followed by a certainty of food, subjects have been found to show little or no preference between the two, provided stimuli presented (after choosing) indicate which outcome will accrue at the end of the delay. By contrast, when stimuli are uninformative of the eventual outcome, a strong preference is found for the alternative that offers the greater amount of food reinforcement. This effect has been studied using signalled and unsignalled probabilistic reinforcement, in several procedures including concurrent-chains procedures.

The concurrent-chains procedure is separated into two distinct parts, the initial link or choice phase and the terminal link or outcome phase. In the initial link, two concurrently available schedules are offered to the subject. Responding in the initial link is reinforced by entry into one of two mutually-exclusive terminal links. Entry into the terminal link is usually signalled by a change in the colour of the keylight, and the other key is darkened and inoperative. Responding in the terminal link is reinforced by primary reinforcement, after a programmed delay. Once reinforcement

has been delivered, an inter-trial interval (ITI) occurs, after which the keylights are illuminated and the cycle begins again.

In concurrent chains, terminal links often differ in terms of the delay to reinforcement, or the magnitude of reinforcement presented at the end of the delay. Preference for a terminal link is measured by relative response rate or relative time spent responding on the alternatives in the initial links, and in these procedures will favour the alternative with shorter delay or greater magnitude of reinforcement. A variation of the concurrent-chains procedure arranges probabilistic scheduling of reinforcement in the terminal link. That is, the probability that a terminal link will end in reinforcement differs between the two alternatives, and is varied over conditions. Such a manipulation allows investigation of probability of reinforcement as a determiner of choice. Typically, preference is shown for the alternative that offers the higher probability of reinforcement (e.g., Kendall, 1974, 1985; Spetch & Dunn, 1987).

Spetch and Dunn (1987) found a consistent preference for the more reliable alternative in conditions where terminal-link stimuli did not signal the outcome of the terminal link. Thus, a further variation on this percentage-reinforcement procedure is to present stimuli in the terminal links that signal which outcome (i.e., reinforcement or no reinforcement) will accrue at the end of the delay. Kendall (1974, 1985) using a percentage-reinforcement procedure, initially established the preference for the more reliable alternative with an unsignalled procedure. He then presented signals in the terminal link that indicated which outcome would occur at the end of the delay. He found that the strong preference initially established for the more reliable alternative

was substantially decreased in the signalled conditions. For some subjects a reversal of preference occurred where they actually showed a preference for the less reliable alternative. Since this initial research many others have replicated and extended it (i.e., Dunn & Spetch, 1990).

In summary, a signalling effect is often reported in percentage-reinforcement procedures. In unsignalled procedures, strong preference is usually established for the reliable alternative, but this preference is reduced (sometimes eliminated or even reversed) by differentially signalling the outcomes in the unreliable alternative (Dunn & Spetch, 1990).

The present experiment was conducted, in part, to replicate the signalling effect (Dunn & Spetch, 1990; Kendall, 1974, 1985; Mazur, 1991, 1993). A second issue addressed by this experiment concerns the generality of the signalling effect. In the studies described above, terminal-link stimuli signalled which of two outcomes (reinforcement or non-reinforcement) would occur at the end of the terminal link. Some of the conditions described below used certain reinforcement ($p(R) = 1.0$) but differential outcomes in terms of reinforcer duration. Specifically, the "unreliable" alternative delivered either a small or a large reinforcer, whereas the "reliable" alternative always delivered a large one. Thus, Experiment 1 asked whether signalling has the same effect on preference when reinforcer *magnitudes* are mixed on the unreliable alternative and fixed on the reliable one. It is known that in unsignalled conditions, birds favour fixed- over mixed-magnitude reinforcers (Hamm & Shettleworth, 1987). It is possible that signalling moderates this preference.

2.2: METHOD

2.2.1: Subjects

Four experimentally naïve pigeons served as subjects and were maintained at approximately 85% of their free-feeding body weights by post-session feeding when necessary. Water and grit were available constantly in their home cages.

2.2.2: Apparatus

One chamber was used in this experiment. It measured approximately 340 x 340 x 320 mm. An interface panel had three keys mounted on it, one in the centre and others 90 mm to either side. The centre key was covered and unable to be pecked. All keys were mounted approximately 210 mm above the grid floor. Responses exceeding approximately 0.15N produced a feedback click from a relay mounted behind the panel. A hopper, containing wheat, was central in the interface panel and approximately 60 mm above the floor. It was raised and illuminated with white light during reinforcement. A houselight was located at the middle of the wall opposite the interface panel, and 70 mm above the floor.

2.2.3: Procedure

Daily sessions consisted of 48 trials of a concurrent chains procedure. In these trials, pigeons made choices between two keys in the initial link on a variable interval (VI) 15 s schedule. Both keys were illuminated white, and terminal link entry was non-independent and determined probabilistically (Stubbs & Pliskoff, 1969). One choice ("unreliable"), made by pecking at the left response key, sometimes resulted in 3.5 s access to wheat at the end of a fixed delay of 15 s, and sometimes resulted in none at the end of the delay. The colour projected onto the response key in this terminal link was sometimes blue and sometimes green. In some conditions, the colours were correlated with the eventual outcome of the trial ("signalled" conditions) while in others they were uncorrelated ("unsignalled" conditions). Another choice in the initial link ("reliable"), made by pecking the right key, always resulted in food (3.5 s) at the end of the terminal link, in which the stimulus was either amber or red.

A change-over delay (COD) of 1.5 s was in effect during the initial links so that terminal link entry could not be obtained from an alternative following a key switch or for any subsequent response that occurred within 1.5 s. An Inter-Trial Interval (ITI) of 10 s was also in effect, during which time the houselight and key lights were extinguished.

The experimental conditions are given in Table 2.1. Table 2.1 presents the probability and expected magnitude of reinforcement in each terminal link. Unless stated in parentheses, the duration of reinforcers was always 3.5 s. The experiment consisted of six conditions and their reversals. The first four conditions were

designed to replicate the signalling effect in probabilistic terminal links. For the unreliable alternative, the outcomes signalled by blue and green varied over conditions. The result of these variations in outcome was some signalled conditions (p(R) = 0 and 1.0, or .33 and .67 for blue and green, respectively) and some unsignalled conditions (p(R) = .5 and .5). For the reliable alternative, red and amber lights always signalled certain, 3.5 s reinforcers at the end of the terminal links.

The remaining conditions were designed to discover whether a signalling effect would occur when reinforcement was certain on the unreliable alternative, but either of two different magnitudes might be presented. The magnitudes used (1.2 s and 2.3 sec access to wheat) were chosen to maintain the same difference in overall expected magnitude of reinforcement for the left and right alternatives as had been used in earlier conditions. In reversals, the contingencies of reinforcement previously used for the left key were arranged for the right, and vice versa. The colour stimuli associated with left and right keys were unchanged. Thus, the red and amber stimuli now signalled uncertain reinforcement (or variable-magnitude reinforcement) and the blue and green colours signalled certain reinforcement.

Table 2.1: Conditions in Experiment 1. The probability, magnitude (in parentheses) and expected magnitude of reinforcement for each alternative. Where magnitude is not shown, it is 3.5 s. An R indicates that the reversal of the condition was also run.

Condition	LEFT KEY			RIGHT KEY		
	Blue	Green	E(M)L	Red	Amber	E(M)R
1	1	1	3.5	1	1	3.5
2 (R)	0	1	1.75	1	1	3.5
3 (R)	.5	.5	1.75	1	1	3.5
4 (R)	.333	.667	1.75	1	1	3.5
5 (R)	1 (1.2s)	1 (2.3s)	1.75	1	1	3.5
6 (R)	1 (1.2 or 2.3)	1 (1.2 or 2.3s)	1.75	1	1	3.5

Subjects experienced conditions in different orders. Two birds (E7 and E8) were trained in unsignalled conditions first and signalled conditions second, whereas E5 and E6 had the reverse. Table 2.2 gives the condition orders and number of sessions for each subject.

Table 2.2: Condition order and number of sessions in each condition, for each subject

	E5	E6		E7	E8
Condition	Number of sessions		Condition	Number of sessions	
1	23	58	1	34	55
2	21	47	3	20	46
3	56	56	2	36	56
4	24	24	4	37	37
5	40	54	5	29	43
6	75	64	6	78	64
4A	48	48	4A	48	48
7 (3R)	52	52	7 (3R)	52	52
8 (4R)	28	28	8 (4R)	28	28
11 (2R)	64	64	11 (2R)	64	64
9 (5R)	32	32	9 (5R)	32	32
10 (6R)	31	31	10 (6R)	31	31

Condition 1 provided a baseline where the probabilities of each possible terminal-link outcome were the same and were indicated by a distinctive signal. The baseline measures were used to assess the effects of reduced reinforcement probability on the unreliable alternative, in the following conditions. In Condition 2, the left terminal-link stimuli, green and blue, signalled whether or not reinforcement occurred at the end of a delay ($p = .5$). Green always signalled the reinforcement outcome (3.5 s) and blue signalled extinction. In Condition 3, the overall probabilities of reinforcement for left and right key terminal links were the same as in Condition 2, however the blue and green stimuli were no longer correlated with the eventual outcome. Specifically, the eventual outcome was not signalled. If the signalling

effect was replicated, preference for the right key in the initial link should be lower in Condition 2 (signalled) than in Condition 3 (unsignalled). In Condition 4, outcomes were signalled again but the difference in probabilities of reinforcement on left-key terminal links was smaller than in Condition 2. Again, the signalling effect would appear as a reduction in preference for the reliable alternative (relative to Condition 3), but the reduction may be smaller since the signalled outcomes are more similar than in Condition 2.

Condition 4 asked whether the effect of signalling still occurred when the probabilities of reinforcement for the left-key terminal links (blue and green) were more similar than the values of 0 and 1 used in Condition 2. Specifically, it arranged two non-zero probabilities of reinforcement (p(R) = .33 for blue and .67 for green) on the left alternative, and two certain reinforcement outcomes of 3.5 s access to wheat on the right alternative. As explained below, this was done in preparation for assessing the effects of signalling different magnitudes (rather than probabilities) of reinforcement. Conditions 5 and 6 addressed the issue of whether the signalling effect would occur when two non-zero magnitudes of reinforcement (instead of the 0 s and 3.5 s magnitudes used in Conditions 1 to 4) were scheduled. For these conditions, magnitudes of 1.2 and 2.3 s (with P(R) = 1) were used. In Condition 5, the two magnitudes were signalled by blue and green terminal-link stimuli, respectively. In Condition 6, the two magnitudes were unsignalled, in that they equally often followed the blue and green stimuli. Using these two magnitudes meant that the difference between the blue and green terminal link outcomes in Condition 5 was reduced relative to that in Condition 2, and this may reduce the magnitude of the signalling effect. For comparison, Condition 4 arranged the same *expected magnitudes* of

reinforcement for blue and for green as Condition 5 but did so with probabilistic 0 and 3.5 s reinforcers instead of certain 1.2 and 2.3 s reinforcers.

2.2.4: Assessment of preference and stability

Preference was assessed using relative initial-link response allocation. Greater response allocation to one key in the initial link is considered to express the subject's preference for the terminal link produced by responses in that initial link. After a minimum of 15 sessions, data from the last 10 sessions was assessed and the condition terminated if preference appeared stable across sessions to visual inspection.

2.3: RESULTS

The data used in analyses were taken from the last five (stable) sessions of each condition. Figure 2.1 shows the log ratios of initial link responses (reliable to unreliable) over the last five sessions of Conditions 1 to 4, for all subjects. The group average is also shown. Note that in the figure, conditions do not appear in order on the horizontal axis.

Data from Conditions 1 to 4 show systematic and consistent changes in preference across conditions, although one subject (Subject E7) quickly developed a strong bias towards the right key that remained throughout the experiment. All subjects were approximately indifferent between the two alternatives in baseline, and

the mean log initial-link response ratio was 0.006. When reinforcement was reduced on the left key (Conditions 2 and 3) strong and clear preferences for the reliable alternative emerged. These preferences were much stronger in the unsignalled condition (Condition 3) than in the signalled condition (Condition 2), with mean log response ratios of .75 and .38, for unsignalled and signalled conditions respectively. Thus, the signalling effect was replicated in conditions where blue and green terminal-link stimuli signalled whether or not reinforcement would occur at the end of the terminal link.

Condition 4 again arranged signalled probabilistic reinforcement outcomes, but the probabilities for blue and green were more similar to one another than they were in Condition 2. Specifically, Condition 4 arranged two probabilistic outcomes on the unreliable alternative; .33 for the blue terminal link, and .67 for the green terminal link. Despite the fact that the two stimuli signalled more similar outcomes in Condition 4, the signalling effect was still observed. Comparing preferences in Conditions 3 and 4, Figure 2.1 shows that all subjects showed reduced preference in Condition 4 (the effect was very small for Bird E7). Further, the magnitude of the signalling effect appeared unchanged. Overall, the level of preference for the reliable alternative was about the same in Condition 4 as in Condition 2.

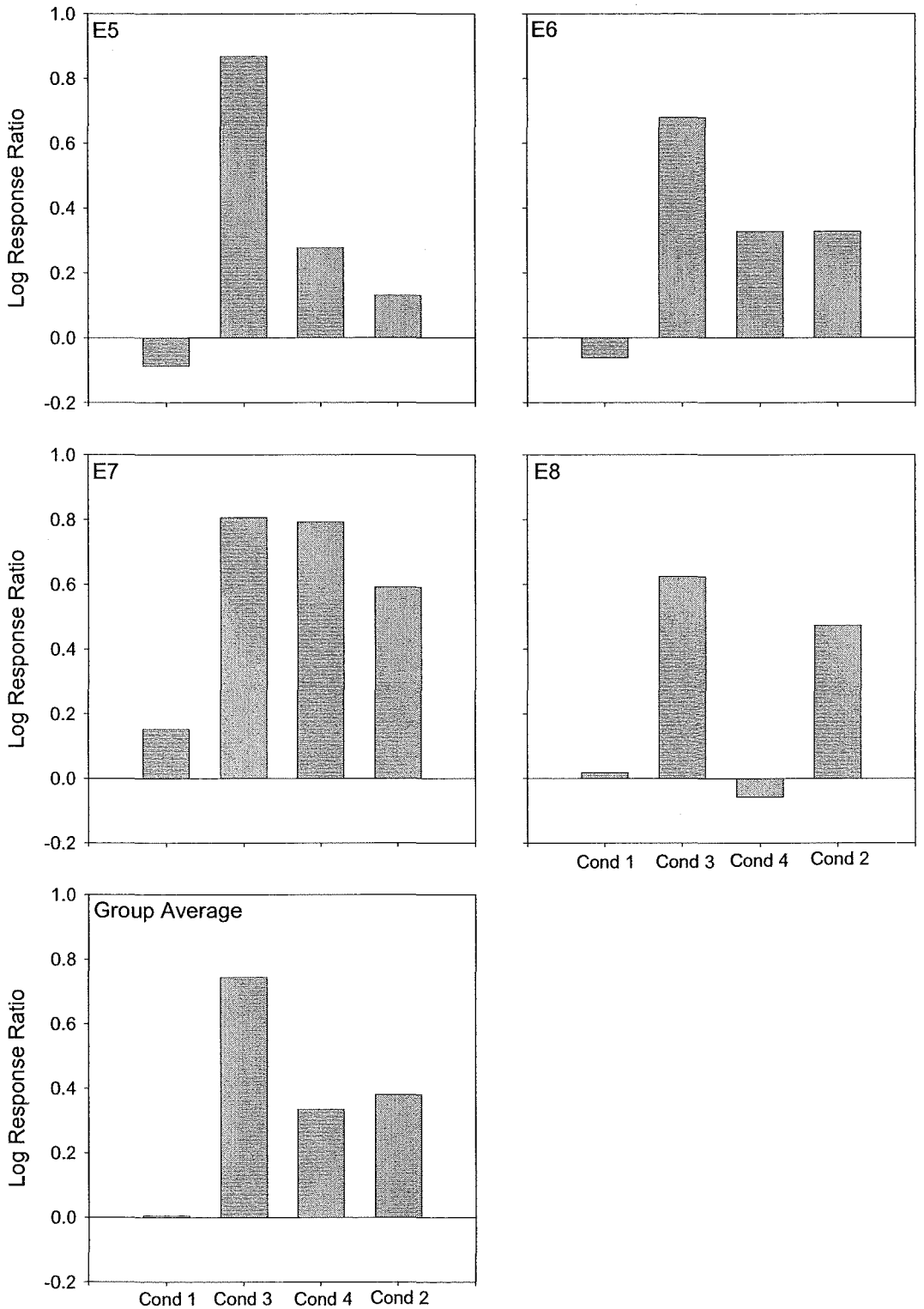

Figure 2.1: Log response ratio for the certain key (Conditions 1 to 4) for individual subjects and the group average.

Conditions 4 to 6 addressed the issue of whether the signalling effect would be maintained when terminal-link stimuli signalled two non-zero magnitudes of reinforcement, rather than different probabilities. Figure 2.2 shows the log response ratio (reliable to unreliable) of initial link responses averaged across the last five sessions in each of these conditions, for each subject. For comparison, the results from Condition 3 (unsignalled probabilistic reinforcement) are also shown, as are the results from a replication of Condition 4 (discussed below).

Condition 6 arranged the same relative expected magnitude of reinforcement for the left and right alternatives, E(M), as Condition 3, but it was constituted differently. Specifically, in Condition 3 probabilities of .5 with magnitudes of 3.5 s were used in the unreliable alternative to constitute the E(M) of 1.75 s reinforcement. In Condition 6, probabilities of 1.0 with magnitudes of 1.2 and 2.3 s were used to constitute the same E(M) of 1.75 s reinforcement. The same level of preference is expected for Conditions 3 and 6, and Figure 2.2 shows that indeed, similar levels of preference were found. This suggests, perhaps that subjects' preferences were equally sensitive to relative probability and to relative magnitude of reinforcement when the outcomes were unsignalled.

In Condition 4, the left key delivered an E(M) of 1.75 s reinforcement by arranging 3.5 s reinforcers at probabilities of .33 and .67. Condition 5 also delivered an E(M) of 1.75 s reinforcement, but did so by arranging certain reinforcers of 1.2 s or 2.3 s duration. Furthermore, the different outcomes were signalled in both cases. If the signalling effect is the same for these types of conditions, then preference will be reduced in Condition 5 (relative to that in the unsignalled Condition 6), and the

reduction will be similar to that in Condition 4 (relative to the unsignalled Condition 3). However, as is evident in Figure 2.2, the reductions in preference with signalling were quite different. Specifically, signalling the two magnitudes had only a very small effect on preference, whereas signalling different probabilities had a larger effect. Across subjects, comparison of preference in Conditions 5 (signalled) and 6 (unsignalled) reveals a consistent, but very small reduction in preference in Condition 5. By contrast, comparison of preferences in Conditions 3 and 4 generally reveals larger changes (although not for Bird E7, who continued to show a large bias favouring the right key), and the group mean data in Figure 2.2 suggest a larger signalling effect for different probabilities than for different magnitudes.

Because this result was somewhat surprising, Condition 4 was replicated after Condition 6 (unsignalled) for all subjects. The original Condition 4 was conducted after an unsignalled condition for two subjects, but for two others it was conducted after Condition 2, in which the two reinforcement probabilities were signalled and very different from one another. It is possible that for these latter two birds, training in Condition 2 reduced preference and that what was observed in Condition 4 was simply a continuation of that performance. However, upon replication it became clear that the signalling effect was the same as in the original Condition 4 (the mean log response ratio was .34 in the replication and .33 in the first determination).

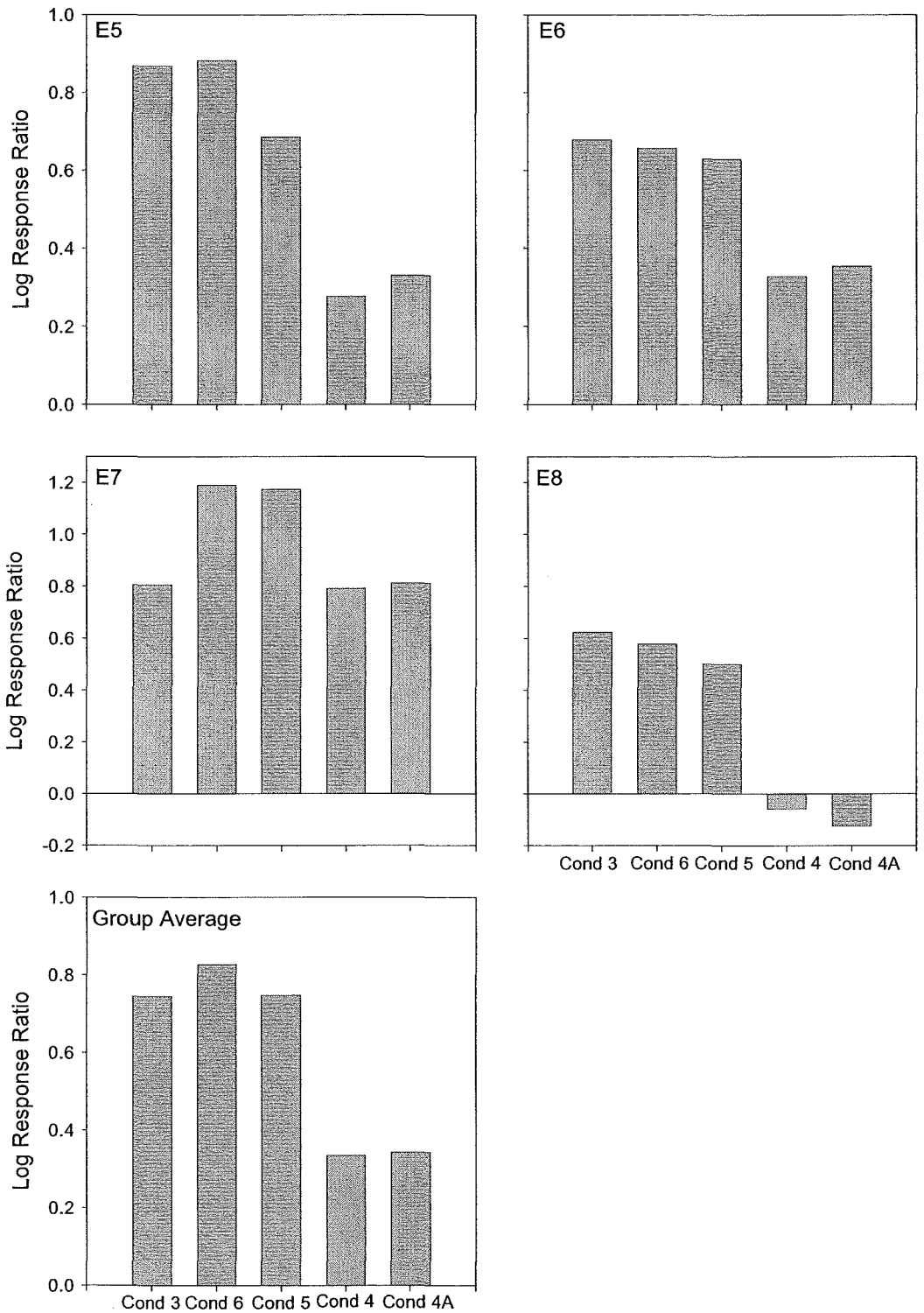

Figure 2.2: Log response ratio for the certain key (Conditions 3 to 6, and Condition 4A) for individual subjects and the group average.

The reinforcement schedules associated with each key were reversed in order to establish if the effects observed were robust and not due to some experimental artefact (e.g., a position bias). Therefore, those schedules that were associated with the left key were now associated with the right key and vice versa. Results from the reversal conditions are presented in Figure 2.3.

Figure 2.3 shows the log response ratio (reliable over unreliable) averaged over the last five sessions of each condition, for each subject. The most noticeable feature of Figure 2.3 is that Bird E7 showed its ever-present bias for the right key. The remaining three subjects reversed their preference, and showed equivalent levels of preferences for the reliable alternative post-reversal. Again, the signalling effect would appear as stronger preference for the reliable alternative in unsignalled conditions relative to the signalled conditions. As is evident in Figure 2.3, the signalling effect was not observed in this series of conditions. Comparing results for Condition 2R (signalled) with those in Condition 3R (unsignalled), only two subjects showed a shift in preference towards the left key (E7 and E8). The remaining two birds showed small shifts in the opposite direction. Neither did the signalling effect appear in Condition 4R. Preference in this condition was overall similar to that in Condition 3R (again, two birds showed greater preference in Condition 4R, but the two others showed the opposite). Preferences in Conditions 5R and 6R were similar, with no consistent differences across subjects. Thus, although preferences for three out of four subjects changed post-reversal, the signalling effect noted before the reversal did not appear – i.e., preference was not stronger in the unsignalled conditions relative to the signalled conditions.

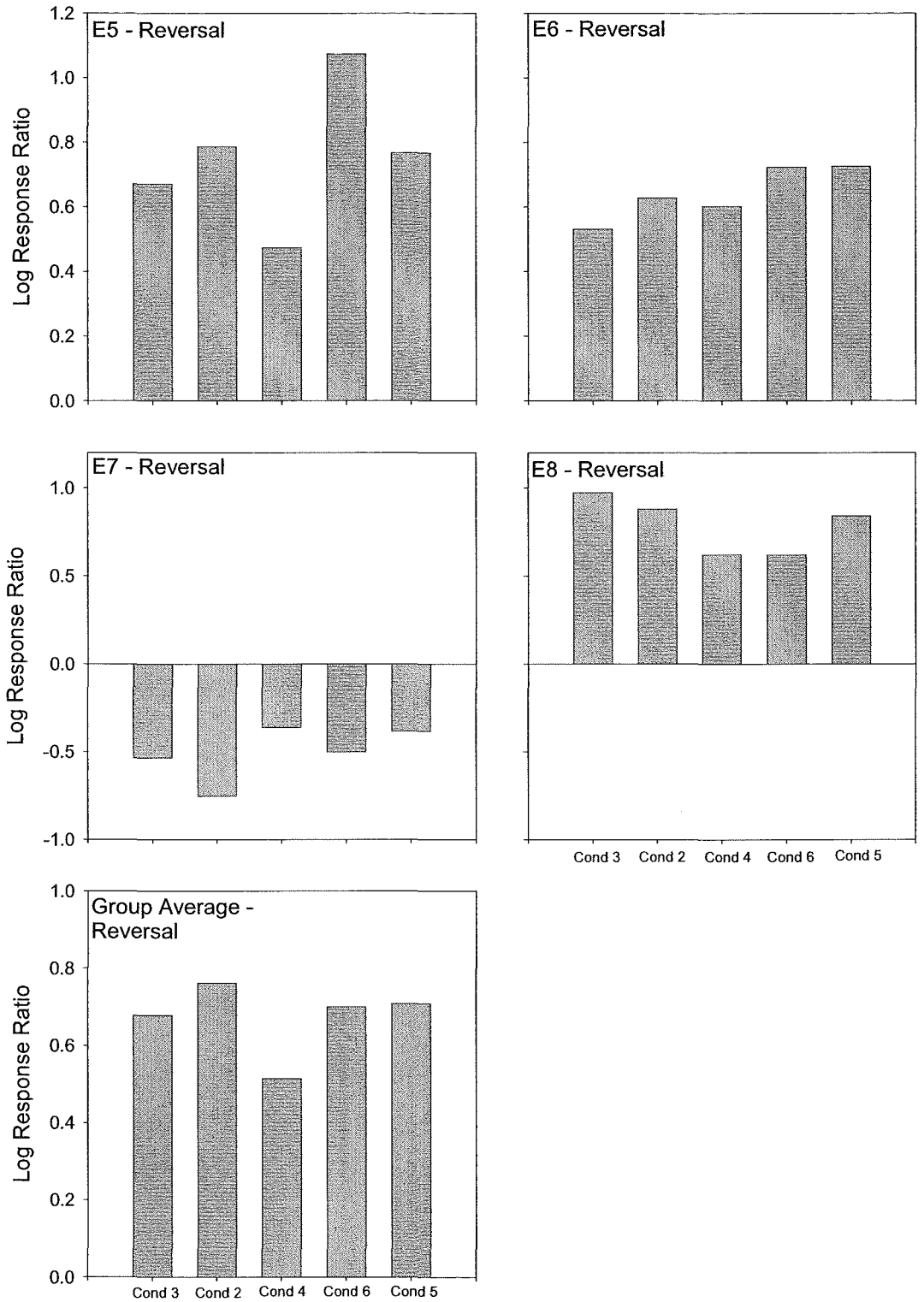

Figure 2.3: Log response ratio (reliable to unreliable) in the reversals of Conditions 1 to 6. Data presented for individual subjects. The group average is also shown.

Further quantitative analyses showed the difference between signalled and unsignalled conditions in the probabilistic and magnitude based conditions more clearly, and uses results from all conditions. Figure 2.4 shows the log response ratios in the last five sessions in the signalled and unsignalled conditions, for each subject, plotted as a function of the log reinforcement ratio (E(M) left / E(M) right). The equations of lines connecting data points are given in each panel. Data are presented separately for the probabilistic and magnitude-based conditions. In this analysis, the signalling effect would appear as less preference (i.e., log response ratios closer to zero) for the signalled conditions at both reinforcer ratios. That is, the descriptive lines would be flatter for signalled than for unsignalled conditions.

The left panels in Figure 2.4 give the results from conditions where different probabilities were used. For all subjects, the slopes of descriptive lines were flatter for the signalled conditions (filled circles) than for unsignalled conditions (unfilled circles), demonstrating the signalling effect. The right panels show the same treatment of results from conditions with different magnitudes of reinforcement. The signalling effect was evident for three out of the four birds (the exception was Bird E8). Interestingly, the sensitivity values were overall greater in the magnitude-based conditions than in the probabilistic conditions. Thus, a lower sensitivity to relative reinforcer magnitude cannot account for the reduced signalling effect in those conditions.

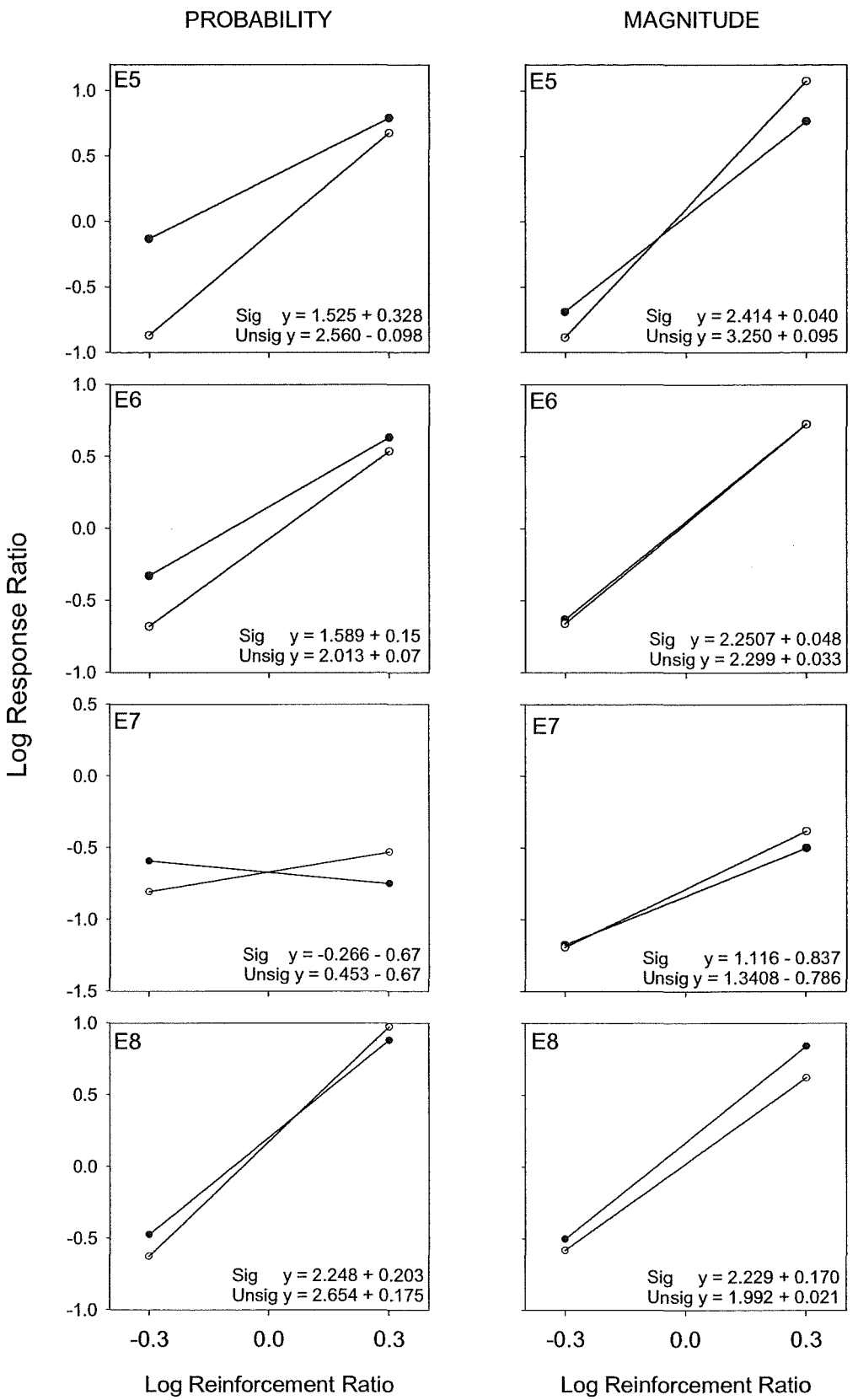

Figure 2.4: Log response ratio plotted against the log reinforcement ratio for the probability and magnitude conditions respectively, for each subject. Filled circles represent data from signalled conditions and unfilled circles represent data from unsignalled conditions. The equation of each line is also shown for both the signalled and unsignalled conditions.

A "signalling effect" index was calculated for the probabilistic and magnitude-based conditions. Log response ratios from the signalled condition were subtracted from the unsignalled conditions. The average index value for the probabilistic conditions was 0.36 (range 0.15 to 0.74), whereas in the magnitude-based conditions it was 0.08 (range 0.02 to 0.20). Thus, the difference between signalled and unsignalled conditions (the signalling effect) was much stronger for probabilistic scheduling.

To summarise, the data support a signalling effect when the terminal-link stimuli signalled whether or not reinforcement would occur at the end of the terminal link. This effect was present, albeit much reduced, when terminal-link stimuli signalled which one of two different-sized reinforcers would occur at the end of the terminal link. The effect was consistent across subjects, with stronger sensitivity in unsignalled than in signalled conditions evident for all four birds in the probabilistic conditions, and for three out of the four birds in the magnitude-based conditions (E8 was the exception with slightly higher sensitivity in the signalled conditions). However, the effect failed to reverse when the reinforcement contingencies associated with each key reversed.

2.4: DISCUSSION

Previous research into the signalling effect has focused on probabilistic scheduling of reinforcement. No previous studies have examined relative magnitude of reinforcement as the main (signalled) independent variable in a signalling procedure. Thus, it is important to establish if the signalling effect applies when other

dimensions of reinforcement, such as magnitude, are signalled. One aim of the current research was to replicate the well-documented signalling effect in a probabilistic concurrent chains procedure – where weaker preference has been found in signalled conditions, relative to that seen in unsignalled conditions. A second aim was to extend that finding to conditions where reinforcement differed in terms of the magnitude (not probability) of reinforcement. To assess the signalling effect, stimuli were presented during the terminal links of some conditions of a concurrent-chains procedure. These stimuli either signalled whether or not reinforcement was forthcoming (probabilistic conditions) or what *amount* of reinforcement was forthcoming (magnitude conditions).

Based on previous research (e.g., Dunn & Spetch, 1990), a signalling effect was expected in the probability-based conditions. However, as magnitude of reinforcement had not previously been signalled in this way, it was not obvious what to expect in the magnitude-based conditions. To summarise the main results, a strong signalling effect was found when reinforcement was probabilistically scheduled and a substantially weaker effect when magnitude of reinforcement was signalled. Overall, there was a consistent decrease in sensitivity to relative reinforcement when differential stimuli signalling the size of reinforcement, were presented in the terminal link of the unreliable alternative. Specifically, sensitivity to relative reinforcement was stronger in unsignalled than in signalled conditions.

It appears that signalling other dimensions of reinforcement, such as reinforcer magnitude, does not result in the signalling effect to the same degree as signalling probabilistic reinforcers does. An implication of these results is that the subjective

value of the terminal-link stimuli, and thus the whole terminal link, may differ depending on which dimension of reinforcement is being signalled. Thus, this finding of a difference in *degree* of the effect is important as it may influence the theoretical explanation of the effect. Several theories of conditioned reinforcement have been applied to the signalling effect, with varying degrees of success. Traditionally, the Delay Reduction Hypothesis and the Uncertainty Reduction Hypothesis (also known as the Information Hypothesis) have both been applied (Fantino, 1977).

Fantino's Delay Reduction Hypothesis (Fantino, 1969; Squires & Fantino, 1971) stated that a terminal-link stimulus acquires conditioned-reinforcement strength when it is correlated with a reduction in time to primary reinforcement. Specifically, preference will become stronger for an alternative with additional conditioned-reinforcement value (from the stimulus), when the stimulus signals a reduction in time, relative to the average time, to primary reinforcement. Spetch and Dunn (1987) applied DRH to choice with probabilistic reinforcement by transforming probabilities of reinforcement into delay values.

Other researchers have also attempted to apply DRH to procedures where mixed magnitudes of reinforcement are delivered. Navarick and Fantino (1972) suggested this application was simply a matter of transforming magnitude values into delay values. They gave an example of how the transformation occurs: they assumed that a terminal link of 5 s duration (FI 5 s) that ends in 4.5 s magnitude of reinforcement is equivalent to an FI 1.7 s terminal link ending with a 1.5 s reinforcer. Given this transformation, the Navarick and Fantino concluded that DRH provides an

adequate prediction of response allocation between two alternatives with different magnitudes of reinforcement.

Yet another theory that has been applied with mixed success to percentage-reinforcement procedures is the Uncertainty Reduction Hypothesis, otherwise known as the Information Hypothesis. It must be acknowledged that this theory has had its detractors, particularly Dinsmoor and Fantino, and their colleagues (e.g., Case & Fantino, 1981; Dinsmoor, Browne & Lawrence, 1972; Fantino, 1977) in the observing response literature. However, with a little manipulation this theory can be adequately applied to the present research.

Traditionally, the information hypothesis stated that for stimuli to acquire conditioned reinforcing strength, they must be informative about forthcoming reinforcement. Where the definition of an 'informative stimulus' is that it must reduce uncertainty about forthcoming events. This applies equally to stimuli that signal reinforcement and to those that signal extinction. Research using observing responses (i.e., Dinsmoor, Browne & Lawrence, 1972) found that stimuli correlated with extinction did not maintain the observing response and therefore did not have any conditioned reinforcing strength. However, more recent research, in particular work on human observing by Case, Fantino and colleagues (i.e., Case, Fantino & Wixted, 1985; Case, Ploog & Fantino, 1990) suggests that an information hypothesis view may be applicable for prediction and explanation of results. They found that the stimuli correlated with non-reinforcement would maintain observing if they could be used to avoid an effortful response. Thus, sometimes stimuli correlated with non-

reinforcement outcomes can be reinforcing, so long as they are useful and indicate how to improve response efficiency.

A revised hypothesis could be proposed, provided it was accompanied by a re-definition of 'informative'. Specifically, the information must be *useful* to the subject. Or put another way, the subject would have to use the information to its benefit[1]. For example, a signal may indicate to the subject that it can omit a possibly effortful response, and this improves response efficiency and thus adds value to the alternative and would therefore become a conditioned reinforcer. This re-vamped information hypothesis could be known as the "optimization hypothesis", as subjects optimize or maximize their performance by using the available information. This idea is consistent with Baum's (1981) use of the term 'net gain' – the energy expended in obtaining reinforcement is taken into account when calculating the amount of reward, therefore the net gain refers to the energy expended subtracted from the reward obtained. In order for subjects to optimize their functioning (their performance in obtaining reinforcement) they need to utilise the (differential) information presented by the signals, and omit possibly effortful responses when it is indicated that reinforcement is not forthcoming.

This theory could be applied specifically to the current experiment. In the signalled, magnitude-based conditions, reinforcement is certain (P(R) = 1), however the magnitude of that reinforcement is uncertain (small or large). The stimuli indicate which of two magnitudes will occur at the end of the terminal link. In order to maximise reinforcement for effort expended, the subject would have to wait by the

[1] Benefit is defined here in a similar way to what Baum (1981) termed 'net gain'. Net gain is determined by weighing the cost and benefit of performing a specified task. Specifically, the cost of performing the task is subtracted from the reward or benefit gained from it.

hopper even for the smaller reinforcer. In the probabilistic conditions on the other hand, the stimuli clearly signalled reinforcement or extinction. Therefore, the subject is able to use the information to improve net gain by performing another behaviour (i.e., grooming) during extinction trials. Using the stimuli in this way results in greater response efficiency, therefore the 'useful' stimulus acquires additional conditioned reinforcement strength, thus improving the overall value of that alternative. In this way, signals in the probabilistic conditions allow greater improvement in the subject's current circumstances than signals in the magnitude-based conditions. Thus, the signals in the probabilistic conditions add greater value to the unreliable alternative than those in the magnitude based conditions. Thus, the signalling effect should be stronger in those conditions. The present results are generally consistent with this position, although it does not explain why similar-sized signalling effects were observed when reinforcer probabilities of .33 and .67 were used.

Another issue to consider is the effect of variability of reinforcement on preference. Research into the variability of reinforcement has found that subjects prefer variable over fixed delays (i.e., Herrnstein, 1964; Mazur, 1991) but prefer fixed over variable magnitudes of reinforcement (i.e., Hamm & Shettleworth, 1987). Following from this latter point, there are two reasons to expect a preference for the reliable alternative in the current experiment. Firstly, the reliable alternative has greater expected magnitude of reinforcement and secondly, the reinforcers associated with the reliable alternative were of fixed magnitude. This raises the question of whether signalling an outcome undermines either or both of these sources of preference. For example, signalling might eliminate the preference for fixed over

mixed magnitudes of reinforcement by making the variable outcomes predictable. Alternatively, signalling may reduce the effectiveness of the different expected magnitudes of reinforcement obtained from the two alternatives. Experiment 2 will pursue this question further.

Finally, it is important to discuss the difficulty obtaining a reversal of the signalling effect following a position reversal. The key issue is whether or not the signalling effect is robust to reversal of the reliable versus unreliable contingencies across response keys. In the present experiment, the effect disappeared when these contingencies were reversed. A literature review of similar procedures with signalled reinforcement contingencies shows that most researchers either did not conduct position reversals, or if they did, did not report the results. A few have conducted and reported reversals, however. Kendall (1974, 1985) included position reversals and reported that three out of four subjects reversed their preference. Kendall also reported that the signalling effect was still present after reversal. Similarly, Belke and Spetch (1994) conducted a reversal for three subjects who they suspected of having a position bias. All three birds reversed their preference (one much more slowly than the others) and the signalling effect was maintained post reversal. Others who conducted reversals obscured the results by collapsing data across reversals. For example, Alsop, Stewart and Honig (1994) conducted position reversals but then collapsed the data across reversals for analysis, making it impossible to establish whether the effects remained after post reversal. Overall, although the majority of studies did not conduct reversals, a small number did so and found that that the signalling effect was still present. It is not clear why this was not the case in the present experiment.

In conclusion, the present study has found that the signalling effect occurs, although to a much reduced extent, when certain but variable-magnitude reinforcement is used at the end of the "unreliable" terminal link. When uncertain outcomes are unsignalled throughout the terminal links, preference is strong but when they are signalled, the preference reduces. There appear to be two possible reasons for the strong preference in unsignalled conditions – a greater expected magnitude, and lower variability, of reinforcement for the reliable alternative – and it is possible that signalling reduces the effectiveness of either or both of these. We shall move next onto Experiment 2, which addresses the issue of variability.

CHAPTER 3: EXPERIMENT 2

3.1: INTRODUCTION

As previously discussed, an important issue in the study of choice is variability of reinforcement. Herrnstein (1964) used a concurrent-chains procedure and found that pigeons preferred variable over fixed delays, when the mean delay to reinforcement across alternatives was equal. This was later confirmed by Mazur (1984) who used a different procedure, the adjusting-delay procedure. Once a preference for variable delays was established, interest turned to whether preference for variability was a general phenomenon. For example, researchers investigated whether mixed magnitudes would be preferred over fixed magnitudes in the same way that variable delays are preferred over fixed delays. Essock and Reese (1974) used rats as subjects and found a preference for variable over fixed reinforcer amounts. However, Staddon and Innis (1966) found no difference in preference for fixed or variable magnitudes when pigeons were used as subjects. More recent research has suggested an opposite preference. Hamm and Shettleworth (1987) found that pigeons preferred fixed over mixed magnitudes of reinforcement. They used a concurrent VI VI procedure and offered pigeons the choice between a fixed magnitude alternative and one with mixed magnitudes. Subjects consistently preferred the fixed alternative. Furthermore, this preference increased when they increased the variability of reinforcement on the mixed alternative.

In summary, Hamm and Shettleworth (1987) provided evidence of a preference for fixed reinforcement magnitude, and showed how that preference can be affected by adjusting the absolute level of variability in reinforcement on the mixed alternative. In support of this finding, data from Davison and Hogsden (1984) revealed that preference was more sensitive to relative expected magnitude when those magnitudes were fixed (i.e., Parts 4 & 5) than when they were mixed (i.e., Parts 1 to 3). Thus it appears that variability of reinforcement is an important determiner of preference.

The present experiment is based on the possibility that the preference for reliable over unreliable reinforcement found in studies using probabilistic reinforcement is partly related to the preference for fixed over mixed magnitudes. This possibility arises because unreliable (probabilistic) reinforcement could be considered mixed magnitude reinforcement (i.e., 0 s or 3.5 s access to wheat). Thus, in studies investigating preference for certain over uncertain reinforcement there are two variables that may be producing a preference for the certain alternative: 1) the greater expected magnitude of reinforcement at that alternative, and 2) the lesser variability in reinforcer magnitude at that alternative. Variability and expected magnitude of reinforcement are confounded in percentage-reinforcement procedures. Thus, in order to study the effects of signalling on either variable, a procedure is needed where these two variables are isolated.

The reasoning presented above raises the question of how signalling affects preference for these two variables – relative expected magnitude and variability of reinforcement. Signalling reinforcement might reduce the preference for the larger

expected magnitude of reinforcement, which would decrease preference for the certain alternative. Such an effect might occur, for example, because the signals might reduce the effectiveness of expected magnitude as a determiner of preference. Alternatively, signalling outcomes might moderate the preference for the fixed magnitude, as signalling makes the mixed magnitudes more predictable, and thus, less "aversive" (relative to fixed magnitudes). This would also reduce the preference for the certain (fixed) alternative.

It may seem that the relative expected magnitude of reinforcement is likely to be the stronger of these two variables in determining preference, and that any contribution from relative variability is likely to be minimal. If so, any effect of signalling on that part of preference that relates to variability must also be small. However, in Davison and Hogsden (1984), sensitivity to relative expected magnitude was quite low when the magnitudes were mixed (i.e., Parts 1 to 3) – sometimes as low as .28 (see Figure 3.1). With variable reinforcer magnitudes, expected magnitude of reinforcement is therefore not a particularly powerful determiner of preference. It may be, then, that the stronger preferences found without signalling in probabilistic procedures arise partly from the relative variability of magnitude, and partly from the relative expected magnitudes.

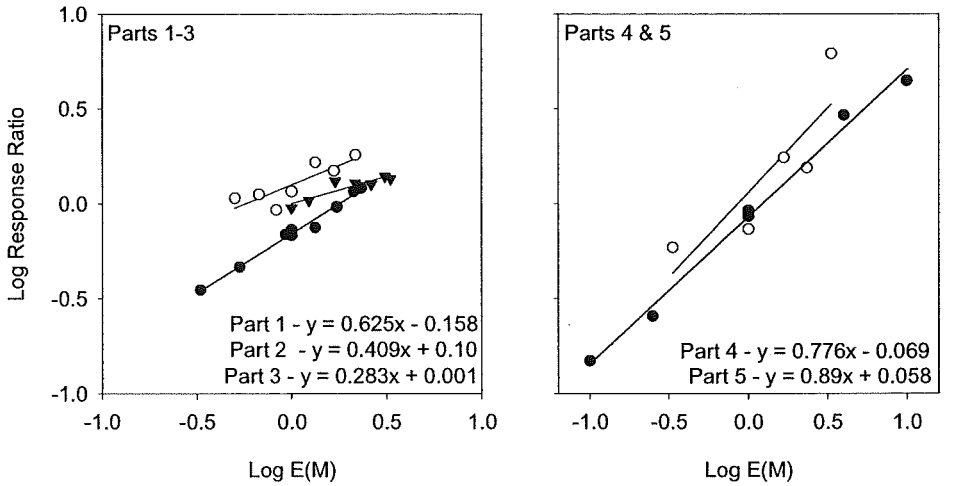

Figure 3.1: Log response ratio plotted as a function of log expected magnitude of reinforcement for all parts in Davison & Hogsden (1984). Lines of best fit and their equations are also shown.

The present experiment seeks to address this issue by presenting signals in the terminal link of a concurrent-chains schedule, in which terminal links differ only in terms of variability in reinforcer magnitude (i.e., relative expected magnitudes of reinforcement were always the same at the two alternatives). The prediction was that signalling will reduce the preference for fixed over variable magnitudes of reinforcement.

3.2: METHOD

3.2.1: Subjects

This experiment used four pigeons previously trained in concurrent VI VI schedules, maintained at approximately 85% of their free-feeding body weights by post-session feeding when necessary. Water and grit were constantly available in their home cages.

3.2.2: Apparatus

Four similar chambers were used in this experiment. They measured 340 x 340 x 320 mm. An Interface panel had three keys mounted on it, one in the centre and one each side (90 mm away), which could be lit with coloured lights. All keys were mounted 210 mm above the grid floor. Responses exceeding approximately 0.15N produced a feedback click from a relay mounted behind the panel. In all chambers, a houselight was mounted in the upper right hand corner. The hopper, containing wheat, was central in the interface panel and approximately 60 mm above the floor. It was raised and illuminated with white light during reinforcement. Reinforcers comprised a number of 1.5-s hopper presentations, each separated by .5 s.

3.2.3: Procedure

A modified concurrent-chains procedure was used. The response keys in the initial links were illuminated with white lights. The initial-link schedules were equal concurrent VI 10 s schedules. Key pecks in the initial links produced access to one of two mutually exclusive terminal links. Initial-link schedules were non-independent, and entry to either terminal link was equally probable (Stubbs & Pliskoff, 1969). A change-over delay (COD) of 1.5 s was in effect during the initial links so that terminal-link entry could not be obtained from an alternative following a key switch or for any subsequent response that occurred within 1.5 s.

Once a terminal link had been entered, the side keys were darkened and the colour projected on the centre key was that associated with the terminal link in effect

at the time – blue, green, red or white. The terminal link was a Fixed Time (FT) 10 s schedule. Reinforcer magnitudes were varied by arranging a series of 1.5 s cycles of the hopper, separated by 0.5 s during which the hopper was lowered and the chamber darkened. Thus, 1, 3, and 5 hopper cycles yielded magnitudes of 1.5, 4.5, and 7.5 s. A 15 s Inter-Trial-Interval (ITI) separated the trials. Table 3.1 shows the conditions, the terminal link stimuli associated with each alternative, and their associated reinforcement magnitudes. Each stimulus was associated with two equally probable reinforcement outcomes, Mag 1 and Mag 2. In some conditions, the two reinforcement outcomes available for a given alternative were the same ("fixed"), in others they were different ("mixed") and in yet others, they were different and differentially signalled by the colours presented on the centre key ("signalled mixed"). Once preference was stable, the position of the contingencies was reversed to the other alternative.

Table 3.1: Experimental conditions, stimuli associated with each terminal link alternative, and the reinforcement magnitudes (in seconds) associated with each terminal link.

	LEFT				RIGHT			
	Stimuli				Stimuli			
	Blue		Green		Red		White	
Cond	Mag1	Mag2	Mag1	Mag2	Mag1	Mag2	Mag1	Mag2
T	7.5	7.5	7.5	7.5	1.5	1.5	1.5	1.5
TR	1.5	1.5	1.5	1.5	7.5	7.5	7.5	7.5
1	1.5	1.5	7.5	7.5	1.5	1.5	7.5	7.5
2	1.5	1.5	7.5	7.5	4.5	4.5	4.5	4.5
2R	4.5	4.5	4.5	4.5	1.5	1.5	7.5	7.5
3	1.5	1.5	7.5	7.5	1.5	7.5	1.5	7.5
3R	1.5	7.5	1.5	7.5	1.5	1.5	7.5	7.5
4	1.5	7.5	1.5	7.5	4.5	4.5	4.5	4.5
4R	4.5	4.5	4.5	4.5	1.5	7.5	1.5	7.5
5	1.5	7.5	1.5	7.5	1.5	1.5	7.5	7.5
5R	1.5	1.5	7.5	7.5	1.5	7.5	1.5	7.5

These subjects did not have experience with reinforcement being presented as numerous hopper cycles. Therefore, they completed two training conditions (T & TR in Table 3.1), to test for control of preference. During these conditions, one alternative delivered a large amount of reinforcement (in the form of five hopper cycles, a total of 7.5 s reinforcement), while the other alternative delivered less (one hopper cycle for a total of 1.5 s reinforcement). In all experimental conditions proper, the expected magnitude of reinforcement (E(M)) was equal across alternatives. The way in which those magnitudes were constituted (i.e., fixed versus mixed) and the terminal link signal conditions (i.e., signalled or unsignalled) differed. Condition 1 was the baseline. In Baseline, both alternatives (Left and Right) led to mixed magnitudes of reinforcement, but the size of the reinforcer earned in a given trial was signalled throughout the terminal link by the colour stimulus (e.g., for the left alternative, 1.5 s reinforcers were signalled by blue, and 7.5 s reinforcers were signalled by green). In Condition 2, the left terminal link remained the same as in Condition 1 (signalled mixed magnitude); however, both magnitudes on the right alternative were fixed at 4.5 s. If subjects prefer fixed over signalled mixed reinforcement, then they would prefer the right alternative in the initial link in Condition 2. Conditions 2 and 4 are to be compared so I will move on to Condition 4 and return to Condition 3 shortly. In Condition 4, the mixed magnitudes on the left alternative were no longer signalled, while the reinforcement magnitudes on the right alternative were fixed. Specifically, the two reinforcement outcomes for the left terminal link (1.5 or 7.5 s) were equally likely to follow either terminal-link stimulus (blue or green). If subjects show a greater preference for fixed over unsignalled mixed than that for fixed over signalled mixed, then preference for the right key in the initial link in Condition 4 should be greater than that in Condition 2.

Returning to Condition 3, the right alternative became unsignalled mixed magnitude, while the left alternative arranged signalled mixed magnitudes. Condition 5 was the reverse of Condition 3. These conditions assess preference between signalled mixed and unsignalled mixed magnitudes. Thus, across conditions, the experiment assessed preferences among fixed magnitudes, signalled mixed magnitudes, and unsignalled mixed magnitudes of reinforcement.

The conditions labelled with an 'R' in Table 3.1 are the reversal conditions, where the position of the reinforcement contingencies was reversed once preference was deemed stable. For some subjects (Q6 and Q8), Conditions 3 and 3R were replicated. The reinforcement contingencies were reversed once more, so that Condition 3 was the same as Condition 5R, and Condition 3R was the same as Condition 5. While these two subjects were completing Conditions 5 and 5R, the other two subjects completed replications of Conditions 4 and 4R with longer terminal link durations (FT 20 s), permitting assessment of any effect on signalling with longer terminal links. A 'terminal-link effect' has been reported where preference for a given alternative becomes stronger with longer terminal links (although the data on the terminal-link effect are somewhat inconsistent). Condition 4 was chosen for the replication as it was the condition expected to produce the strongest level of preference, therefore if the terminal-link duration was to have an effect, it should be most apparent in Condition 4.

3.2.4: Order of conditions: Three subjects completed the two training conditions (T and TR in Table 3.2; one subject was new to the group after the first Q6 died). All four subjects completed baseline (Condition 1 in Table 3.2). From Condition 1, each

subject went on to a different condition, and then its reversal. As shown in Table 3.2, each subject continued through the experimental conditions in a different order. As discussed, two subjects (Q5 and Q7) completed the experimental conditions proper relatively quickly so they went on to replicate Conditions 4 and 4R, with longer terminal links (T TL in Table 3.2).

Table 3.2: The order of conditions for each subject.

Q5	Q6	Q7	Q8
T		T	T
TR		TR	TR
1	1	1	1
2	3	4	3R
2R	3R	4R	3
4	5R	2	5R
4R	5	2R	5
3	4	3R	2
3R	4R	3	2R
4 (L TL)	2	4R (L TL)	4
4R (L TL)	2R	4 (L TL)	4R

After a minimum of 15 sessions, data from the last ten sessions was assessed and the condition terminated if preference appeared stable across sessions to visual inspection.

3.3: RESULTS

The results of the training conditions are shown in Figure 3.2. Figure 3.2 shows the log response ratios as a function of log expected magnitude of reinforcement, averaged over the last five sessions in the two training conditions, for

three subjects (Q5, Q7 & Q8). The group average is also shown. The equations of descriptive lines connecting data points are given for each subject. Subject Q6 died during these conditions and the new subject did not experience the training; rather, it was placed in an autoshaping procedure until responding was established. Once responding was established, it began in Condition 1. The analyses showed that control of preference by relative magnitude, (with different magnitudes constituted with a number of hopper cycles), was obtained. The average sensitivity value to relative magnitude (excluding Q6) was 1.04, with a range of 0.73 to 1.27.

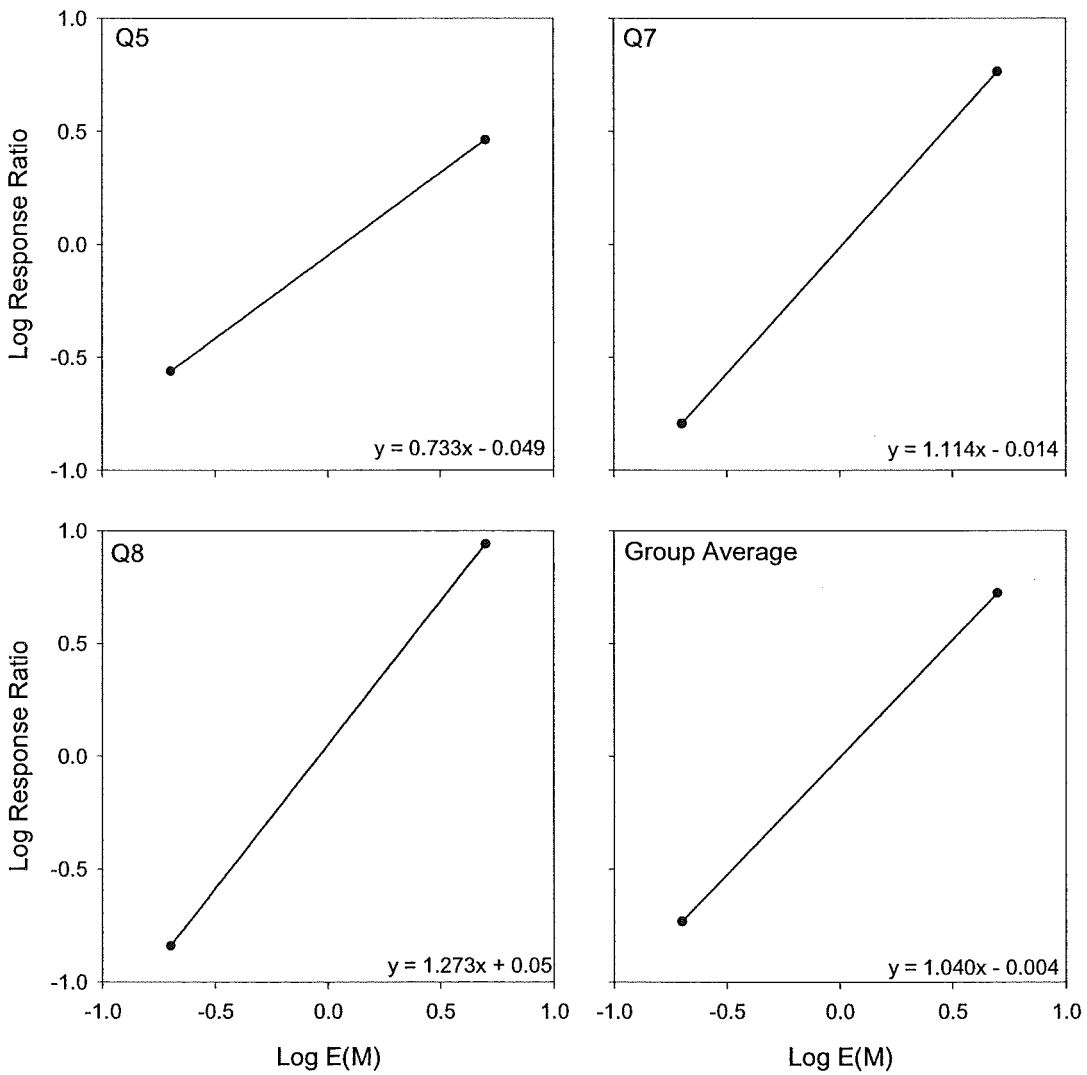

Figure 3.2: The log response ratio plotted as a function of log relative expected magnitude (number of hopper cycles), averaged across the last five sessions of the training conditions, for Subjects Q5, Q7 & Q8, and the group average. Regression analyses and equations are also shown.

The main results of the experiment proper are shown in Table 3.3. The number of sessions in each condition and the choice proportion (left) averaged over the last five sessions of each condition are shown for each subject.

Table 3.3: The number of sessions of training (sx#) in each condition, for each subject. The choice proportion (CP), averaged over the last five sessions, is also shown.

	Q5		Q6		Q7		Q8	
Cond	**sx #**	**CP**	**sx #**	**CP**	**sx #**	**CP**	**sx #**	**CP**
T	80	0.74			69	0.85	69	0.90
T R	66	0.22			77	0.14	77	0.13
1	37	0.47	33	0.55	37	0.45	37	0.45
2	28	0.49	30	0.59	31	0.55	29	0.32
2R	30	0.51	31	0.45	33	0.51	36	0.38
3	29	0.51	30	0.39	37	0.56	45	0.47
3R	40	0.42	38	0.35	29	0.42	26	0.38
4	38	0.52	36	0.31	46	0.50	32	0.28
4R	33	0.64	32	0.44	33	0.7o	29	0.39
5			33	0.31	29	0.42	28	0.41
5R			29	0.48	37	0.56	30	0.41

The data used in analysis were relative initial-link response rates, averaged across the last five sessions of each condition. For those subjects that experienced both Conditions 3 and 5 (and their replications), because relative initial-link response rates for Conditions 3 & 5R, and for Conditions 3R & 5 did not differ systematically, they were averaged to obtain one data point for each, referred to as Conditions 3 and 3R in Table 3.4. The individual and group average choice proportions are shown.

Table 3.4: The choice proportion (left) averaged over the last five sessions of each condition, for each subject. The group average choice proportion is also shown.

Cond	Q5	Q6	Q7	Q8	Av
1	0.47	0.55	0.45	0.45	0.48
2	0.49	0.59	0.55	0.32	0.49
2R	0.51	0.45	0.51	0.38	0.46
3	0.51	0.43	0.56	0.44	0.49
3R	0.42	0.33	0.42	0.39	0.39
4	0.52	0.31	0.50	0.28	0.40
4R	0.64	0.44	0.70	0.38	0.54

As shown in Table 3.4, the average choice proportion for Condition 1 (Baseline) was .48. The choice proportions for individual subjects ranged from .45 to .55, indicating approximate indifference. Condition 2 involved signalled, mixed magnitudes of reinforcement on the left and fixed magnitudes of reinforcement on the right alternative. Thus, Condition 2 was a direct comparison of fixed versus mixed reinforcement. The average choice proportion in Condition 2 was .49, a slight preference towards the right (fixed) alternative. However, the shift in preference from baseline was not reliable across subjects; three showed small increases in preference for the left, and only Bird Q8 showed the expected increase in preference for the right (now fixed magnitude). Similarly, when conditions were reversed and the fixed alternative was the left key, response proportions did not change systematically: two birds showed an increased preference for the left alternative (Birds Q5 and Q8) while the remaining two subjects showed decreases in preference for the left. Thus, these data show no tendency for subjects to prefer fixed-magnitude reinforcement over (signalled) mixed-magnitude reinforcement.

Comparing results for Conditions 2 and 4, Table 3.4 shows that some birds preferred the fixed alternative but some the mixed alternative. This suggests only

inconsistent preference for the fixed alternative when comparing preference in conditions that were conducted, separated in time by some distance. On the other hand, Table 3.4 shows that for all four birds, preference shifted reasonably strongly when contingencies were reversed in Condition 4, suggesting preference is more sensitive when conditions are conducted closer in time. It may be that across conditions, preference shifted for some birds (particularly Q5) for reasons not controlled in the experiment, and that the comparison of adjacent conditions is a more sensitive measure of preference. Accordingly, for the remaining conditions, the strength of preference for an alternative was assessed in the same way – i.e., by measuring the extent to which response proportions changed when conditions were reversed.

Conditions 3 and 3R permit assessment of preference between signalled and unsignalled mixed-magnitude reinforcement. In Condition 3, the left alternative offered signalled mixed-magnitude reinforcement and the right offered unsignalled mixed-magnitude reinforcement. The group average response proportion was 0.49 (approximately indifference), but upon reversal (Condition 3R), the group average revealed a shift in preference toward the right key. Examining the shift in preference between Conditions 3 and 3R reveals that every subject showed a shift in preference towards the right key when compared pre-reversal versus post-reversal. This shift shows that signalled mixed-magnitude reinforcement was preferred over unsignalled mixed-magnitude reinforcement, and the extent of the preference (based on group averages) was about 10%. Figure 3.3 (left panel) shows the preferences for individual subjects for Conditions 3 and 3R.

Comparison of Conditions 4 and 4R permits assessment of preference between unsignalled mixed magnitudes and fixed magnitudes. In Condition 4, the left alternative offered unsignalled mixed magnitudes and the right alternative offered fixed magnitudes. In Condition 4R, the contingencies were reversed so that the left alternative offered the fixed magnitudes and the right alternative offered the mixed magnitudes. Examination of the shift in preference between Conditions 4 and 4R revealed that each individual subject showed a shift in preference toward the fixed (left) alternative post reversal. This shift demonstrates that fixed magnitudes were preferred over unsignalled mixed-magnitudes. On average, the extent of that preference was approximately 14% when pre- and post-reversal preference is compared.

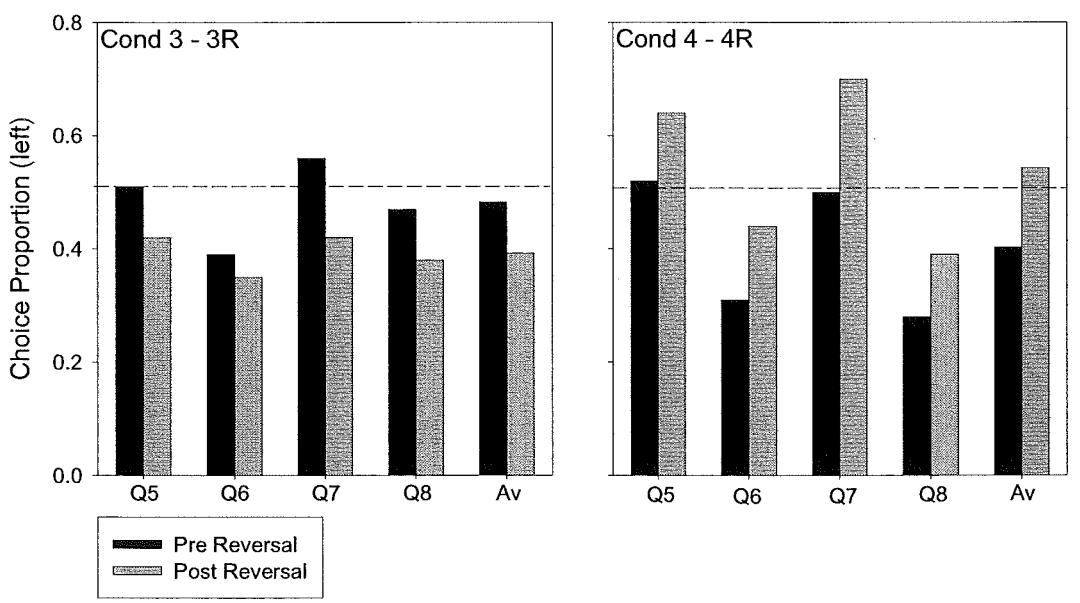

Figure 3.3: Choice proportion for the left alternative for each subject, in Conditions 3 and 3R, and Conditions 4 and 4R. The group average choice proportion is shown. The darks bars represent preference pre reversal, and the light bars represent preference post reversal. The line of indifference (0.5) is shown as a dashed line.

The highest level of preference for the fixed alternative was expected to be found in Condition 4, with less preference expected in Condition 2. If subjects show a greater preference for fixed (over unsignalled mixed) than that for fixed (over signalled mixed), then preference for the fixed (right) alternative in the initial link in Condition 4 should be greater than in Condition 2. Figure 3.4 illustrates that this is true for three subjects (Q5 was the exception, with similar levels of preference obtained in both conditions). However, the shift in preference between Conditions 2 and 2R is weaker than the shift between Conditions 4 and 4R for all birds (the solid lines in Figure 3.4 are flatter than the dotted lines), which suggests that sensitivity is reduced in the signalled conditions (Conditions 2 and 2R) relative to the unsignalled conditions (Conditions 4 and 4R).

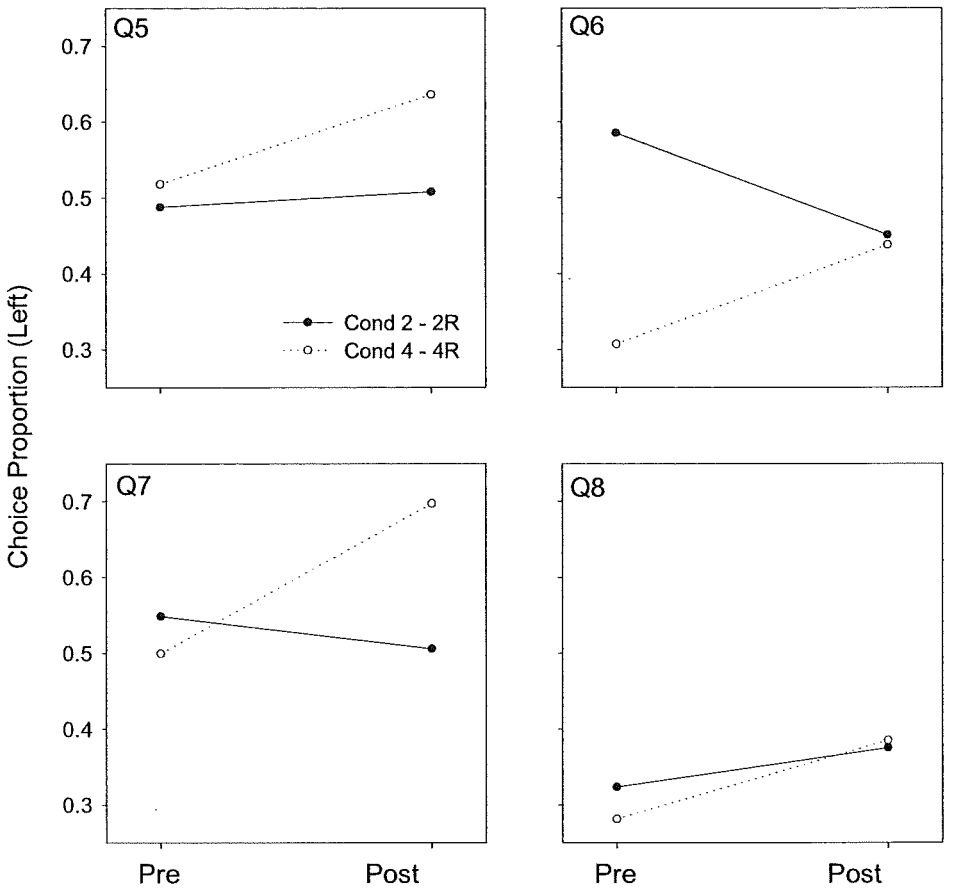

Figure 3.4: Preference for the left alternative in Conditions 2 and 2R (solid line with filled circles), and in Conditions 4 and 4R (dotted line with unfilled circles) for all subjects.

Based on the above analyses, we can place these conditions in order of preference. Fixed magnitudes of reinforcement were preferred over unsignalled mixed magnitudes, fixed magnitudes of reinforcement were equally preferred to signalled mixed magnitudes, and signalled mixed magnitudes were preferred over unsignalled mixed magnitudes. Thus, these results confirmed the reported preference for fixed magnitudes (Hamm & Shettleworth, 1987) and they confirmed that signalling reinforcement outcomes in the mixed-magnitude alternative reduces that preference.

While reasonably orderly results were obtained in this experiment, the sizes of preferences were generally very modest, although they were larger than those obtained in the magnitude-based series of conditions in Experiment 1. Furthermore, the terminal-link duration in this experiment (10 s) was short relative to the initial links (VI 10 s), and it is possible that this feature of the procedure was responsible for the small preferences shown by subjects. As mentioned earlier, two subjects (Q5 & Q7) completed replications of Conditions 4 and 4R with 20 s terminal links to assess whether a 'terminal-link effect', where stronger preference is obtained with longer terminal links, would be found (Grace & Bragason, 2004; MacEwen, 1972). However, very similar levels of preference were found in each condition, for each subject, in the replication (4 & 4R for Bird Q5, and 4R & 4 for Bird Q7). Thus, there was no effect on preference of increasing terminal-link duration.

3.4: DISCUSSION

Previous research has shown that subjects prefer fixed over unsignalled mixed magnitudes of reinforcement, and that the greater the variability of reinforcer magnitude at the mixed alternative, the greater the preference (Hamm & Shettleworth, 1987). It is possible that signalling in probabilistic reinforcement procedures actually reduces a preference for fixed magnitudes (at the certain alternative) over mixed (i.e., uncertain) magnitudes, resulting in a reduced preference for certain over uncertain reinforcement. It may be that the preference for fixed over variable magnitudes has more to do with the unpredictability of the magnitude of upcoming reinforcement than its variable size per se. Therefore, Experiment 2 was designed to ask whether signalling affects preference between alternatives that differ only in terms of

variability of reinforcement (i.e., expected magnitude of reinforcement was the same for the two alternatives).

The results of this experiment confirmed that signalling which of the two mixed magnitudes of reinforcement will occur at the end of the trial does indeed reduce preference for fixed over mixed magnitudes of reinforcement. Condition 4 and its reversal showed that preference shifted toward the fixed-magnitude alternative, by about 14%, when the fixed outcomes were shifted to the left and the unsignalled mixed-magnitude outcomes were shifted to the right, confirming Hamm and Shettleworth's (1987) conclusion. Similar results were obtained when unsignalled and signalled mixed-magnitude reinforcers were compared, suggesting that signalled mixed are preferred over unsignalled mixed to about the same extent as fixed magnitudes are preferred over unsignalled mixed ones. Condition 3 and its reversal showed a shift in preference of about 10% when the signalled mixed-magnitude alternative was shifted from the right key to the left, and unsignalled mixed magnitude reinforcement was shifted to the right, showing that signalled mixed-magnitude outcomes are preferred over unsignalled ones. Finally, the direct comparison of signalled mixed and fixed revealed no preference, indicating that signalling the mixed outcomes eliminated preference. There was, however, a greater preference for every subject when fixed versus unsignalled mixed outcomes were compared than when unsignalled mixed and signalled mixed outcomes were compared. This suggests that the three outcomes used in this experiment may be ordered in terms of preference as follows: fixed, signalled mixed, unsignalled mixed. These results confirm that variability of reinforcement may need to be accounted for as a separate independent variable. This has implications for models of choice, as

most of them currently do not include a parameter for relative variability. However, researchers have used the harmonic means of reinforcement variables in order to account for preference for variability (Killeen, 1968; delay to reinforcement).

Returning to the question raised earlier: it is possible that signalling is not only acting on the preference for fixed magnitudes, but that it is also having an effect on the preference for the larger expected magnitude of reinforcement. Experiment 2 has addressed the issue regarding relative variability of reinforcement. The following experiment, Experiment 3, addresses the issue regarding relative expected magnitude.

CHAPTER 4: EXPERIMENT 3

4.1: INTRODUCTION

The reasoning presented earlier identifies two variables that support preference for certain over uncertain reinforcement. These are the relative expected magnitude of reinforcement (which is greater for the "certain" alternative), and relative variability of reinforcer magnitude (which is greater for the "uncertain" alternative). Signalling the outcome that will occur at the end of a terminal link reduces sensitivity of preference to one, or both, of these variables, but it is unknown which. Experiment 2 showed that signalling moderates the preference for the fixed magnitude, but it is possible that it also moderates preference for the greater expected magnitude.

In Experiment 2, the expected magnitude of reinforcement was the same and relative variability differed across alternatives. One alternative always offered a fixed magnitude of reinforcement, while the other alternative sometimes delivered a small reinforcer and sometimes delivered a large reinforcer. In some conditions, terminal-link stimuli indicated which of those two outcomes would occur at the end of the delay. This permitted assessment of the effects of signalling on preference for alternatives differing in relative variability of reinforcement. The results indicate that sensitivity to relative variability of reinforcement is affected by signalling reinforcement outcomes in the terminal links. Experiment 2 revealed a preference for the fixed alternative when compared with an unsignalled mixed-magnitude

alternative. However, when the magnitudes on the mixed alternative were signalled, and fixed on the other alternative, subjects were approximately indifferent between the two. Thus, a reduction in preference for the fixed alternative was shown when the outcomes on the mixed-magnitude alternative were signalled. These data confirm relative variability as an important determiner of choice, and show that its effects are moderated by signalling.

The present experiment seeks to answer the question of whether signalling reinforcement outcomes affects sensitivity of preference to relative expected magnitudes of reinforcement when terminal links end in reinforcers that differ in terms of relative expected magnitude but are the same in terms of variability. This experiment involves a different procedure from the first two experiments – a two-component (within-session reversal) procedure is utilised in order to minimise the effect of any variability of responding session to session.

4.2: METHOD

4.2.1: Subjects

The same four pigeons were used in this experiment as were used in Experiment 2. They were maintained at approximately 85% of their free-feeding body weights by post-session feeding when necessary. Water and grit were constantly available in their home cages.

4.2.2: Apparatus

The same four chambers were used in this experiment as in Experiment 2.

4.2.3: Procedure

No additional training was required as subjects had experienced a similar procedure in Experiment 2. However, two variations were introduced into the procedure used in the present experiment. First, data from Experiment 2 showed clearer differences in preference for conditions conducted consecutively (remember comparison of Conditions 2 and 4, and their reversals in Experiment 2). Hence, in the present experiment, the reinforcement outcomes were reversed in separate halves of the sessions, and preference was studied separately for the two halves. Second, because of equipment limitations different stimuli were used for terminal-link outcomes in the present experiment, as explained below.

A multiple concurrent-chains procedure was used, with two components presented during the session. Each component consisted of 24 trials, separated by a 15 s inter-trial interval, with a total of 48 trials per session. In one component the terminal-link stimuli and the reinforcement contingencies associated with that component, were from the left alternative; conversely in the other component, they were from the right alternative. Thus, the components involved reversal of the position of the reinforcement contingencies. The components were differentiated from one another by the colour of the response keys in the initial link. Specifically, in Component 1 the response keys were lit green in the initial links, and in Component 2

red response keys were used in the initial links. A 3 min blackout separated the two components.

The initial-link schedules were equal concurrent VI 10 s schedules. The response keys in the initial links were illuminated with green or red lights (as described above). Key pecks in the initial links produced access to one of two mutually-exclusive terminal links. A COD of 1.5 s was in effect during the initial links so that reinforcement could not be obtained from an alternative if the first response after switching between alternatives occurred within 1.5 s. Entry to either terminal link was equally probable (Stubbs & Pliskoff, 1969).

Once a terminal link had been entered, the side keys were darkened and the colour projected on the centre key was that associated with the terminal link in effect at the time. The terminal link was a Fixed Time (FT) 20 s schedule. Reinforcement was constituted of a number of 1.5 s hopper cycles; each hopper cycle was separated by .5 s. Relative expected magnitude differed across alternatives, where one delivered a small expected magnitude (2.25 s) and the other, a large expected magnitude (6.75 s). Expected magnitude on each alternative was made up of two magnitudes (Mag 1 and Mag 2). On the lean alternative, these were one and two hopper cycles, yielding reinforcers of 1.5 and 3 s, averaging 2.25 s access to wheat per reinforcer. On the rich alternative, the two magnitudes used were three and six hopper cycles, yielding reinforcers of 4.5 and 9 s, averaging 6.75 s access to wheat per reinforcer. The ratio of hopper cycles presented by Mag 1 and Mag 2 was 1:2 for each alternative and hence relative variability of reinforcement was the same.

The position of the lean and rich alternatives at the start of a session was counterbalanced across subjects. Two birds (Q5 and Q7) experienced the rich alternative on the left first, while the other two birds (Q6 and Q8) experienced the rich alternative on the right first. The position was then reversed for each bird in the second component of the session.

This experiment involved two conditions each continuing for 30 sessions, with either signalled or unsignalled terminal links. As mentioned, once a terminal link was entered, the colour projected on to the centre key was associated with the terminal-link schedule in effect at that time. For two birds the colour produced by the left alternative was white in the first half of the session and blue in the second half. For the other two birds, these were reversed. The same procedure for determining the colour projected onto the response was used for the right alternative, except the colours were green and amber. In the unsignalled condition, the same stimulus was presented for both Mag 1 and Mag 2 on each alternative. That is, the same stimulus was presented for both the smaller and larger reinforcers. In the signalled condition, on the other hand, a flashing houselight (.25 s on, .25 s off) in the terminal link accompanied one of the magnitudes on each alternative. Specifically, for two birds (Q5 and Q7) the houselight flashed in terminal links ending with the smaller reinforcer. For the other two birds (Q6 and Q8), the houselight flashed in terminal links ending with the larger reinforcer. The order of signalled and unsignalled conditions was also counterbalanced. Birds (Q5 and Q8) were placed in the unsignalled condition first and birds (Q6 and Q7) were placed in the signalled condition first.

4.3: RESULTS

After 30 sessions of training had been completed and performance assessed as stable, the average choice proportion (left) for the last five sessions of each component was calculated. Table 4.1 shows the choice proportions for each component, for each subject. The group average is also shown. As Table 4.1 highlights, very high levels of preference were obtained for all subjects. All subjects strongly preferred the left alternative when the left was the richer alternative; conversely all subjects strongly preferred the right when it was the richest component. The level of preference obtained in the two components of a session was comparable. This shows that preference was sensitive to changes during the session. No effects of order or position of component presentation were evident.

The choice proportions were quite similar in the signalled and unsignalled conditions; however, for seven out of eight individual comparisons, choice proportions were more extreme in the unsignalled condition. There was one exception (Subject Q5) who displayed greater preference for the rich, right alternative in the signalled than in the unsignalled component. Overall, this result is consistent with the signalling effect, whereby greater preference is found in the unsignalled relative to the signalled condition. However, any effects found in this experiment were not as strong as those in the previous two experiments.

Table 4.1: Choice proportion (Left) averaged over the last ten sessions of each condition, in the signalled and unsignalled conditions. Individual choice proportions are shown for each component; the group averages are also shown.

Bird	Signalled		Unsignalled	
	L rich comp	R rich comp	L rich comp	R rich comp
Q5	0.75	0.15	0.78	0.29
Q6	0.83	0.14	0.88	0.08
Q7	0.76	0.37	0.8	0.25
Q8	0.75	0.27	0.79	0.17
Average	**0.77**	**0.23**	**0.81**	**0.20**

A generalised-matching analysis was conducted to assess the level of sensitivity to relative expected magnitude. The results of this analysis are shown in Figure 4.1, where the log response ratio is plotted as a function of the log expected magnitude ratio for all subjects. Matching analysis revealed that although the level of preference obtained was approximately equal in both signalled and unsignalled conditions, for three out of four birds sensitivity to relative E(M) was greater in the unsignalled condition. Generalised-matching analysis conducted with the group average data revealed a small signalling effect: greater sensitivity to relative expected magnitude in the unsignalled relative to the signalled condition.

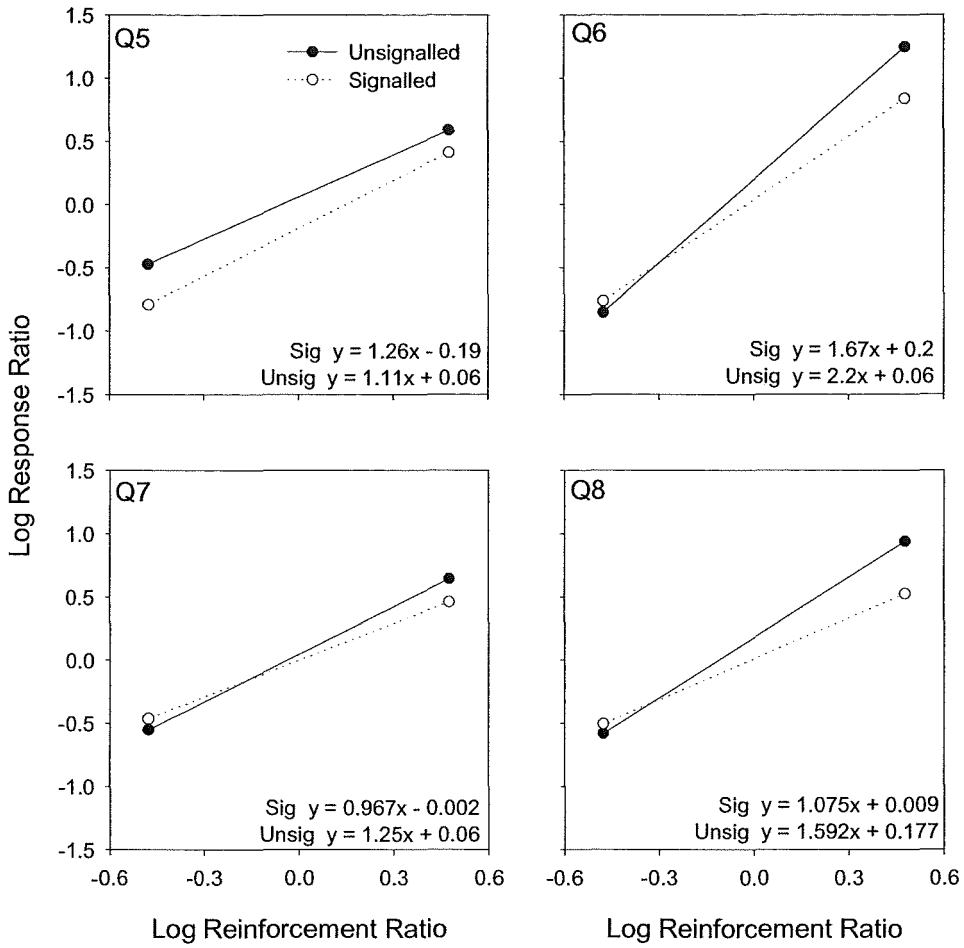

Figure 4.1: Log response ratio plotted as a function of log ratio of expected magnitude of reinforcement, for individual subjects. Matching analysis is also shown. Open circles represent the signalled condition, and filled circles represent the unsignalled condition.

4.4: DISCUSSION

Experiment 3 was designed to ask whether signalling affects preference between alternatives that differ only in terms of relative expected magnitude (i.e., when all other aspects of reinforcement were constant). This experiment complements Experiment 2, which was designed to assess the effects of signalling on preference between alternatives differing in variability of reinforcement, while holding relative expected magnitude constant. The present experiment held relative

variability of reinforcement constant while varying relative expected magnitude. Thus, the aim of the current experiment was to assess the effects of signalling on preference for alternatives differing in expected magnitude.

Upon analysis of relative responding, a small signalling effect was observed where a stronger level of preference was obtained in the unsignalled relative to the signalled conditions. This result was supported by the generalised-matching analyses, which revealed stronger sensitivity to relative expected magnitude in the unsignalled relative to signalled condition. However, the results were not consistent across subjects. Moreover, both effects were relatively small compared to the effects obtained in Experiment 2. Although results from these two experiments will be directly compared, remember that procedural differences may contribute to the size of the signalling effect. Specifically, it might be that the two-component procedure used in this experiment may result in stronger effects than those seen in the previous two experiments.

Previous research (i.e., Hamm & Shettleworth, 1987) has confirmed that pigeons prefer fixed magnitudes of reinforcement. Results of Experiment 2 indicated that signalling acts on that preference, possibly by reducing the effect of variability in magnitude of reinforcement on preference. Results of this experiment suggest that when the relative variability of reinforcement is held constant and relative expected magnitude varied, there is very little change in preference when the alternatives are signalled or otherwise. Therefore, signalling appears to have a greater influence over preference when the relative variability of reinforcement is signalled than when the relative expected magnitude is signalled.

Initially, it was thought that the signalling effect might only occur with probabilistic reinforcement. The question remained, what was it about signalling probability that resulted in such an effect? One possibility was that pigeons prefer fixed magnitudes of reinforcement but probabilistic reinforcement is inherently variable. Signalling the probabilistic outcomes might reduce this variability and thus the preference for the fixed alternative. Therefore, Experiment 2 was conducted to determine whether a preference for fixed magnitudes of reinforcement would be affected by signalling. Analysis showed that signalling does reduce the preference for fixed magnitudes. It follows therefore that it is the variable nature of probabilistic reinforcement that signalling is influencing. However, in both Experiments 2 and 3, the signalling effect also occurs when certain reinforcement (P(R) = 1) is arranged. Firstly, in Experiment 2, the reinforcement on both alternatives was certain but variable on one alternative. Thus, variability of reinforcement was isolated as an independent variable. Secondly, in Experiment 3, reinforcement was again arranged with certainty, but the relative variability of reinforcement was held constant while relative expected magnitude varied. The signalling effect was evident although much reduced in the present experiment. Therefore, when relative reinforcement is variable, probabilistic or not, signalling seems to have its largest effect.

Thus far, we can identify that signalling reduces preference for fixed reinforcer magnitudes (Experiment 2). It is difficult to determine how signalling is having its effect and it would be helpful to also understand where exactly signalling is having its effect. The Contextual Choice Model (CCM) might help us here by permitting assessment of how signalling affects sensitivity to various parameters of reinforcement.

To investigate this more explicitly, we would need to vary *both* relative probability and another dimension of reinforcement. It is necessary to manipulate at least two dimensions of reinforcement so that we can identify the effects of signalling one dimension on sensitivity to the other. For example, we could vary both relative probability and immediacy of reinforcement, signal only the probability of reinforcement, and assess the effects of that signalling on sensitivity to both dimensions of reinforcement. By conducting experiments in this way, we can assess what effect signalling has on sensitivity to all dimensions of reinforcement, not simply the variable that has been explicitly signalled.

One possibility raised by signalling two or more reinforcement variables, is that signalling has a broader or global effect on sensitivity of behaviour. An experiment that enables the measurement of sensitivity in a signalled procedure where multiple reinforcement variables are manipulated, may shed light on the nature of the signalling effect and the way in which it affects preference.

Although much research has been conducted into probabilistic scheduling of reinforcement and signalling, to our knowledge there have been no parametric investigations of the signalling effect manipulating reinforcer probability, delay and magnitude. It is essential to any research area to have a sound understanding of the way in which preference is affected by variations of reinforcement, and when multiple dimensions of reinforcement are varied simultaneously. Thus from here, we change course considerably, and move onto two parametric experiments with the aim of further investigating the possible global effects of signalling when more than one dimension of reinforcement is varied at once within a signalling procedure. Not only

will a parametric investigation indicate the degree to which variables of reinforcement have independent effects on preference, such an experiment may also help to answer whether signalling has global effects on sensitivity.

CHAPTER 5: EXPERIMENT 4

Signalled and Unsignalled Terminal Links in Concurrent Chains: I. Effects of Reinforcer Probability and Immediacy

5.1: INTRODUCTION

Herrnstein (1964) investigated the generality of the matching relation to responding maintained by conditioned rather than primary reinforcement, using the concurrent chains procedure introduced by Autor (1960/1969). Davison (1983) suggested that the CGML might be applied to data from a concurrent chains procedure, but noted that sensitivity to terminal-link immediacy and magnitude varied as a function of overall initial- and terminal-link durations. Later, Grace (1994) proposed a model (Contextual Choice Model, CCM) based on the matching law that attempted to resolve the problems with the CGML noted by Davison (1983).

The novel feature of CCM is the additional exponent *Tt* / *Ti*, the ratio of the average terminal- and initial-link durations, which means that sensitivity to immediacy and magnitude of reinforcement will depend on temporal context. Inclusion of this exponent permits CCM to deal with the initial- and terminal-link effects previously reported in the literature (i.e., Fantino, 1969; MacEwen, 1972).

One of the most important assumptions of the concatenated matching law is that effects of different variables on choice such as rate, immediacy and magnitude of reinforcement, are independent. This assumption has been tested in a variety of

studies that have manipulated different combinations of these variables parametrically (e.g., Grace, 1995; Grace, Bedell, & Nevin, 2001; McLean & Blampied, 2001), and the general conclusion is that independence has been supported when relative, but not absolute, levels of reinforcer variables have been manipulated (see Berg & Grace, 2004, for review). However, one variable that has not received much attention in these parametric studies is reinforcer probability. Although it is well established that pigeons' initial-link preference in concurrent chains between terminal links associated with the same delay favours the alternative that delivers food with greater probability (e.g., Spetch & Dunn, 1987), no prior study has investigated reinforcer probability parametrically and in combination with other reinforcer variables. Such a study could provide a test of whether effects of probability are additive and independent when combined with other reinforcer variables.

The concurrent-chains procedure has been used to study signalling in percentage-reinforcement procedures. With unsignalled terminal links, the typical result is that response allocation favours the alternative associated with the highest reinforcer probability (e.g., Fantino, Dunn & Meck, 1979; Kendall, 1974, 1985; Spetch & Dunn, 1987). However, with signalled terminal links, a reduced preference for the more reliable alternative has been reported (e.g., Dunn & Spetch, 1990; Kendall, 1974, 1985; see also Experiment 1). This attenuation in preference implies a reduction in sensitivity to reinforcer probability, known as the 'signalling effect'. Because no prior studies have examined the effects of probability in combination with other reinforcer variables, it is unknown whether signalling outcomes affects only sensitivity to probability, or might also affect sensitivity to other reinforcer variables.

The aim of the present study was to investigate whether effects of reinforcer probability and immediacy on choice were additive and independent, for both signalled and unsignalled percentage reinforcement procedures. By varying reinforcer immediacy and probability across series of signalled and unsignalled conditions, it was planned to test whether signalling terminal-link reinforcer outcomes affected sensitivity to reinforcer immediacy as well as probability of reinforcement.

Pigeons were exposed to three different concurrent-chains components in each session, similar to Grace (1995) and Grace, Bedell and Nevin (2001). The initial-link schedules were constant across components and conditions. For one group of subjects, the initial links were independent concurrent VI 30 s VI 30 s, whereas for the other group a VI 15 s schedule was used that guaranteed that the terminal links were entered equally often (interdependent scheduling; Stubbs & Pliskoff, 1969). Components were distinguished by the colour used for all stimuli (red, green, white). In the red component, the terminal-link schedules were fixed time (FT) 10 s FT 20 s, in the green component the schedules were FT 20 s FT 10 s, and in the white component the schedules were FT 15 s FT 15 s. Within each condition, the terminal-link reinforcer probabilities were constant across components, but were varied across conditions to yield probability ratios of 5:1, 1:5, 2:1, and 1:2. Two sets of conditions were arranged in which the terminal-link outcomes were either signalled or unsignalled. In signalled conditions, a flashing houselight accompanied terminal-link presentations that ended without food delivery, whereas, in unsignalled conditions the houselight was always illuminated during the terminal links. Thus, this design allowed us to examine the effects of parametric variation in relative reinforcer

probability at different levels of relative immediacy, for both signalled and unsignalled terminal links.

5.2: METHOD

5.2.1: Subjects

Eight mixed breed pigeons, numbered 161-164 and 185-188, served as subjects. They were maintained at 85% of free-feeding body weights (± 15g) by post-session feeding when necessary. They were housed individually in a vivarium with a 12:12 hr light/dark cycle (lights on at 0700h), and with free access to grit and water. All had previous experience with a variety of experimental procedures.

5.2.2: Apparatus

Eight standard three-key operant chambers were used, measuring 350 mm deep by 360 mm wide by 350 mm high. The response keys were located 260 mm above the floor and arranged in a row. A houselight was arranged 70 mm above the centre key and a grain magazine with an aperture (60 mm by 50 mm) was located 130 mm below the centre key. The grain magazine was illuminated when reinforcement was made available. A force of approximately 0.10 N was required to operate each response key, and effective responses produced an audible feedback click. Chambers were enclosed in a sound-attenuated box, and ventilation and white noise was provided by an attached fan. The experiment was controlled and data collected using a MEDSTATE® notation program and a MED-PC® system interfaced to an IBM®-compatible microcomputer that was located in an adjacent room.

5.2.3: Procedure

Because all subjects had previous experience in a variety of procedures, training began immediately in the first condition. Sessions were conducted daily at the same time (1100h & 1200h) with few exceptions. There were two groups of subjects. For one group, independent scheduling was used for the initial links whereas for the other, interdependent scheduling was used. For both groups, a three-component concurrent chains procedure was employed. Each component was differentiated by the colour of keylights associated with the components (i.e., red, green and white). Components were presented in random order in each session. Each component consisted of 24 trials, thus there were 72 trials per session. Each component was separated by 3 min blackout period. The houselight provided general illumination at all other times, except when reinforcement was being delivered and during no-food terminal links in the signalled conditions (see below).

5.2.4: Concurrent Chains. At the beginning of each trial (a trial is one complete initial- and terminal-link cycle) the side keys were illuminated with the colour associated with that component, signifying the initial link (choice phase) of the procedure. For one group of subjects, a VI 15 s schedule operated in the initial links. Terminal-link entry was randomly assigned to either the left or the right key (Stubbs & Pliskoff, 1969), with the restriction that three out of every six cycles were assigned to each key. The VI 15 s schedule contained 12 intervals constructed from an arithmetic progression, $a, a + d, a + 2d, \ldots,$ in which a equals one twelfth and d equals one sixth of the schedule value. An interval was sampled randomly without replacement from the list at the start of a cycle, and separate lists were maintained for cycles in which entry into the left and right terminal links was arranged. The initial-

link VI timer began timing after the first response to either key. There was no changeover delay (COD). When the initial-link VI schedule had timed out, the next response to that key resulted in terminal-link entry. For another group of subjects, concurrent independent VI 30 s VI 30 s schedules operated during the initial links. These schedules also comprised 12 intervals constructed from an arithmetic progression and were sampled without replacement. At the start of a component, intervals were sampled from both schedules; thereafter, an interval was sampled when terminal-link entry was gained for a particular alternative. As above, both schedules began timing in a cycle after the first response to either key. The first response to a key after its schedule had timed out produced entry into the corresponding terminal link. When either terminal link was entered, timing for both initial-link schedules stopped.

For both groups of subjects, terminal-link entry was signalled by a change from constant to flashing illumination on that key (i.e., 0.25 s off, 0.25 s on). The other key was darkened and responses to it had no scheduled consequence. Terminal links provided access to grain or a blackout of equivalent duration, independently of responding, after a delay according to a FT schedule. Whether reinforcement or blackout occurred at the end of the delay was determined probabilistically (see below). During reinforcement, the grain magazine (or hopper) was raised and illuminated for 3 s.

Different pairs of terminal-link schedules were used for the left and right alternatives in each component: FT 10 s FT 20 s in the Red component; FT 20 s FT 10 s in the Green component; and FT 15 s FT 15 s in the White component. Thus,

immediacy ratios were 2:1, 1:2, and 1:1 across components. These schedules remained unchanged throughout the experiment. The same pair of reinforcer probabilities was used across components in each condition, either 67% 33%; 33% 67%; 83% 17% or 17% 83%, corresponding to probability ratios of 2:1, 1:2, 5:1, and 1:5. Probabilities were implemented by selecting from a list without replacement such that out of every 12 terminal links, reinforcement would be delivered ten times (and blackout occurred twice) when the probability was 83%, eight times (and four blackouts) when it was 67%, four times (and eight blackouts) when it was 33%, and two times (and ten blackouts) when it was 17%. The four probability ratios were varied across eight conditions (four signalled and four unsignalled).

Table 5.1 lists the conditions, including the components and their associated delays and probabilities, and whether or not the condition was signalled. These components involved either signalled or unsignalled terminal links. In the unsignalled conditions, the stimulus (flashing keylight) was the same for each occurrence of a particular terminal link, regardless whether food or blackout occurred on that trial. However, in the signalled conditions, a flashing houselight (0.25 s on, 0.25 s off) accompanied each terminal link that ended in blackout. In these conditions, the houselight flashed in phase with the flashing keylight.

The order of conditions was counterbalanced across subjects. Thus, each subject began the experiment in a condition associated with a different probability ratio. Half the subjects experienced the four signalled conditions first and the other half experienced the four unsignalled conditions first.

Table 5.1: Conditions, terminal-link signalling (Y for signalled, N for not signalled) and their associated probabilities of reinforcement. Terminal-link delays are shown for each component (Red, Green and White). Each terminal link is associated with 3 s magnitude of reinforcement.

		Red		Green		White	
Cond	Sig	FT 10	FT 20	FT 20	FT 10	FT 15	FT 15
1	Y	67%	33%	67%	33%	67%	33%
2	Y	33%	67%	33%	67%	33%	67%
3	Y	83%	17%	83%	17%	83%	17%
4	Y	17%	83%	17%	83%	17%	83%
5	N	67%	33%	67%	33%	67%	33%
6	N	33%	67%	33%	67%	33%	67%
7	N	83%	17%	83%	17%	83%	17%
8	N	17%	83%	17%	83%	17%	83%

Training in each condition continued for between 39 and 45 sessions. A formal stability criterion was not employed, because in prior studies using multiple concurrent chains, this amount of training was sufficient for response allocation to stabilise. Table 5.2 lists the order of conditions and number of sessions of training for all subjects.

Table 5.2: Order of conditions for all subjects. Number of sessions is given in parentheses.

Pigeon	Cond	Pigeon	Cond	Pigeon	Cond	Pigeon	Cond
161	1 (39)	162	6 (39)	163	3 (39)	164	8 (39)
	2 (40)		5 (40)		4 (40)		7 (40)
	3 (40)		8 (40)		1 (40)		6 (40)
	4 (40)		7 (40)		2 (40)		5 (40)
	5 (40)		2 (40)		7 (40)		4 (40)
	6 (40)		1 (40)		8 (40)		3 (40)
	7 (40)		4 (40)		5 (40)		2 (40)
	8 (40)		3 (40)		6 (40)		1 (40)
185	1 (40)	186	6 (40)	187	3 (40)	188	8 (40)
	2 (45)		5 (45)		4 (45)		7 (45)
	3 (41)		8 (41)		1 (41)		6 (41)
	4 (41)		7 (41)		2 (41)		5 (41)
	5 (41)		2 (41)		7 (41)		4 (41)
	6 (41)		1 (41)		8 (41)		3 (41)
	7 (40)		4 (40)		5 (40)		2 (40)
	8 (40)		3 (40)		6 (40)		1 (40)

5.3: RESULTS

Because no formal stability criterion was used, analyses were conducted to determine if response allocation was changing systematically prior to condition completion. First, for each component and condition, the log initial-link response ratios were regressed on session number across the last ten sessions. The sign of the log ratio was reversed for those conditions in which the terminal-link schedule was richer for the right alternative. Thus, for all conditions, positive slopes would indicate that response allocation was becoming more extreme over the last 10 sessions.

Overall, 96 slopes were computed across subjects, components and conditions, for both groups. For the independent-scheduling group, 54 slopes were positive and 42 were negative (sign test, *ns*). The overall slope averaged across subjects was 0.008. For the interdependent group, 49 were positive and 47 were negative (sign test, *ns*). The overall slope averaged across the four birds was 0.004. This suggests that for all subjects, response allocation did not change systematically across the last ten sessions of each condition.

Because the programmed average initial- and terminal-link delays were constant (and equal) across conditions, CCM simplifies to the generalised matching law. Thus, the following logarithmic form of the generalised matching law was used, including a term for relative reinforcer probability (P), for analysis of initial-link response allocation:

$$\log\frac{B_1}{B_2} = a_r \log\left(\frac{R_1}{R_2}\right) + a_d \log\left(\frac{1/D_1}{1/D_2}\right) + a_m \log\left(\frac{M_1}{M_2}\right) + a_p \log\left(\frac{P_1}{P_2}\right) + \log c \qquad (5.1)$$

Initial-link responses and terminal-link entries and reinforcers were summed across the last ten sessions of each condition, for each component. With independent initial-link schedules, the relative rate of terminal-link entries can vary depending on the subject's behavior. As response allocation becomes more extreme, the relative terminal-link entry frequency favours the richer alternative, creating a positive feedback situation because relatively greater entry frequency has been shown to affect response allocation (Berg & Grace, 2004; Squires & Fantino, 1971). Although the effect of unequal terminal-link entries can be 'corrected' (by subtracting log entry ratios from log response ratios, which effectively assumes that sensitivity to relative entry rate equals 1; Grace, 1999), raw data are shown in Figures 5.1 and 5.2 below. Analyses described later suggest that these results are robust to changes in sensitivity to entry rate.

Figures 5.1 and 5.2 show data from the independent-scheduling group, Pigeons 185 to 188, in the unsignalled and signalled conditions respectively. Figure 5.1 shows the log response ratio as a function of the log probability ratio in the unsignalled conditions for the four subjects in the independent-scheduling group. As is evident in Figure 5.1, all subjects showed high levels of sensitivity to relative probability of reinforcement, in each component, when the terminal links were unsignalled. Individual sensitivity values averaged across components were 1.67, 2.28, 1.79 and 1.77, for Pigeons 185, 186, 187 and 188, respectively, with an overall average value of 1.88.

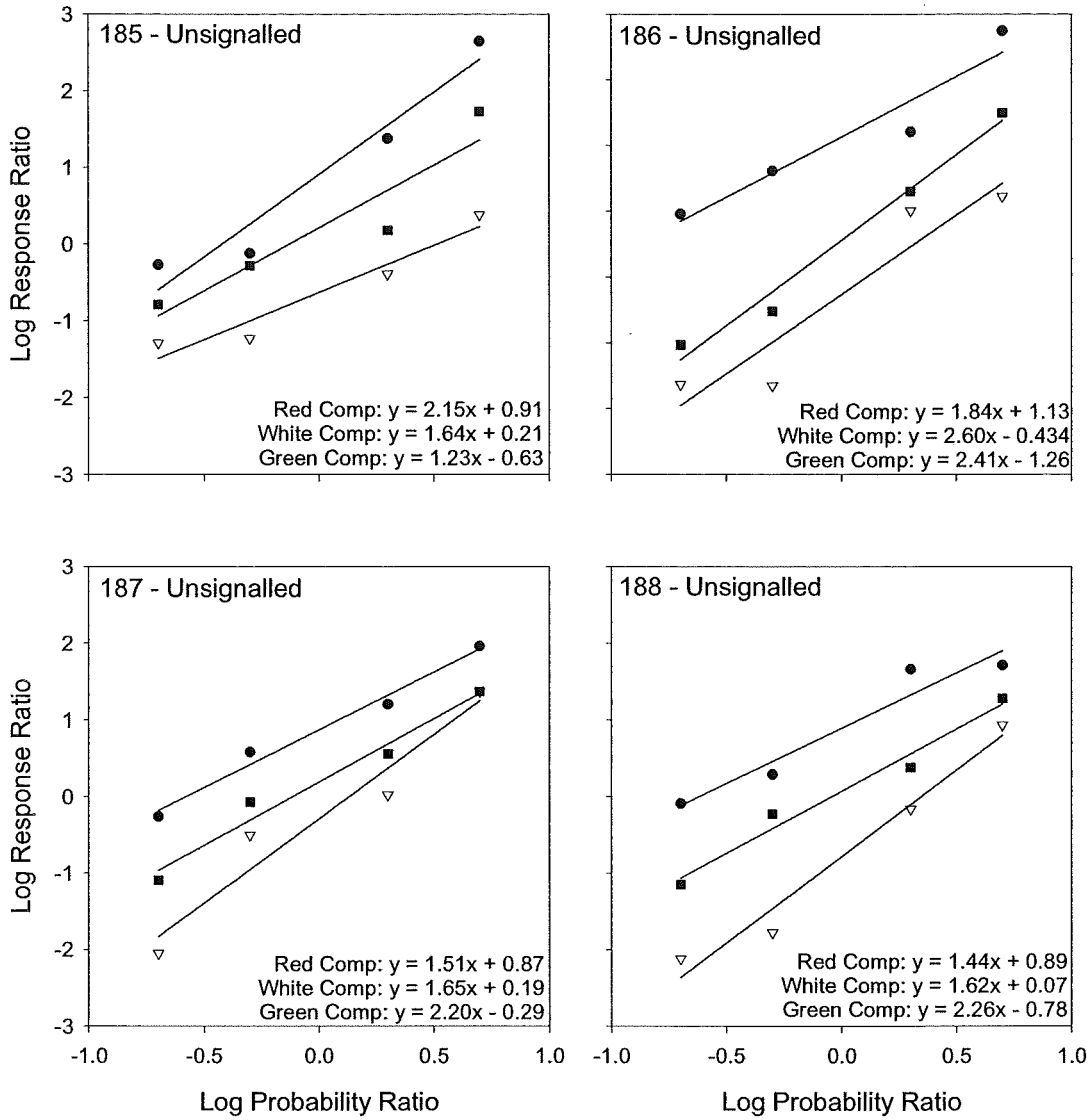

Figure 5.1: Log initial-link response ratios are plotted against log probability ratios in the unsignalled conditions, for subjects in the independent-scheduling group. GML equations are shown for each subject for the red, white and green components, respectively. Filled circles represent red components, filled squares represent white components and open triangles represent green components.

Figure 5.2 shows the log initial-link response ratio as a function of the log probability ratio in the signalled conditions for the same four subjects in the independent scheduling group. The sensitivity values obtained in the unsignalled conditions were higher than those obtained in the signalled conditions. Individual sensitivity values averaged across components were 0.69, 1.26, 1.76 and 1.53 for Pigeons 185, 186, 187 and 188, respectively, with an overall average value of 1.31.

For nine out of 12 cases, sensitivity values were lower in signalled relative to unsignalled components. One subject (Pigeon 188) showed greater sensitivity in unsignalled conditions in two out of three components and one subject (Pigeon 187), in one out of three components.

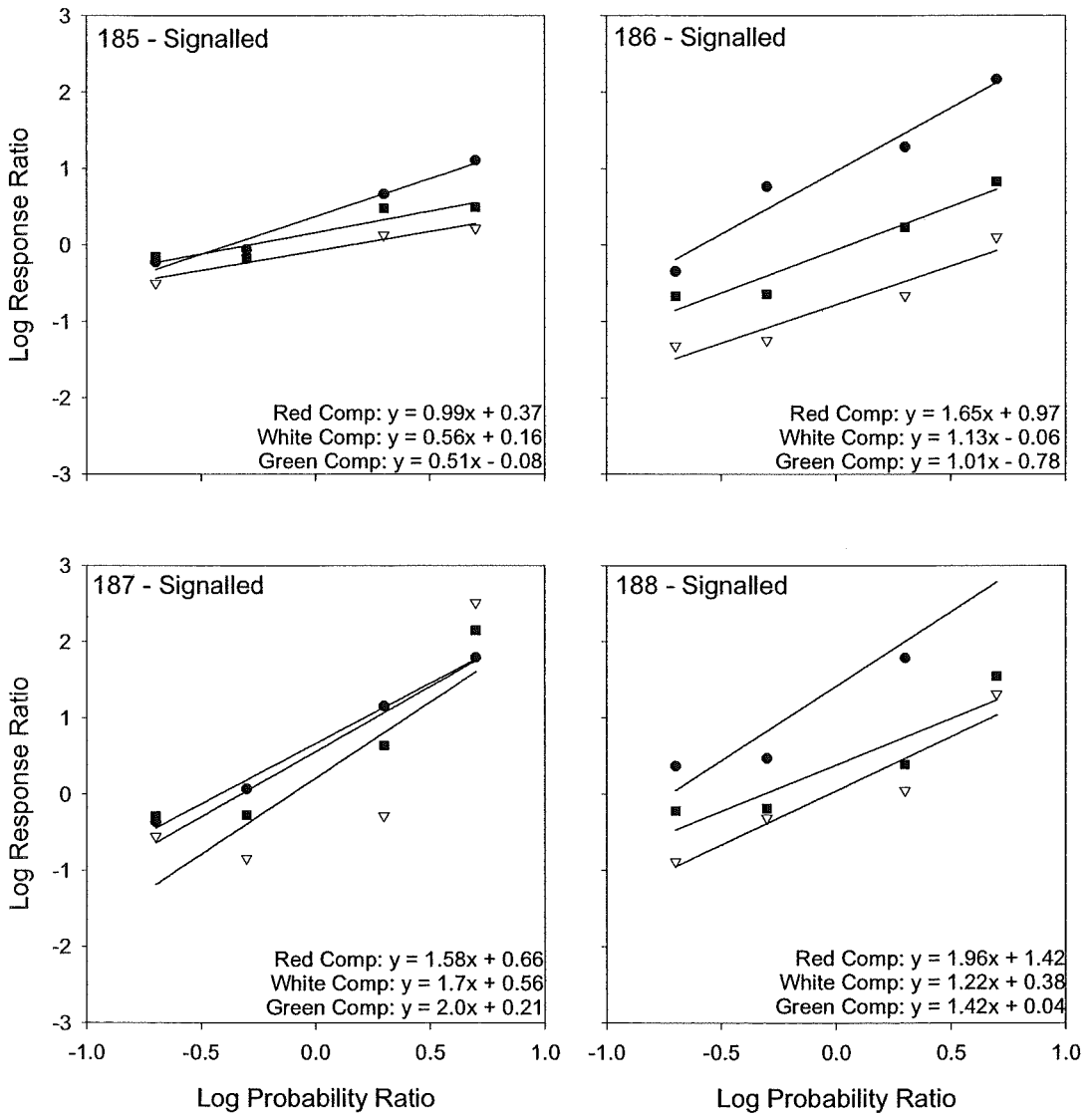

Figure 5.2: Log initial-link response ratios are plotted against log probability ratios in the signalled conditions, for subjects in the independent-scheduling group. GML equations are shown for each subject for the red, white and green components, respectively. Filled circles represent red components, filled squares represent white components and open triangles represent green components.

Sensitivity to relative immediacy is demonstrated by the differences in bias (regression-line intercepts) across components in Figures 5.1 and 5.2. Specifically, an estimate of sensitivity to immediacy was obtained by subtracting the *y*-intercept value of the regression slope in the green component from that of the red component, and dividing by 2*log(2); using the following equation: (log B_L/B_R (Red) – log B_L/B_R (Green)) / 2*log2. The individual sensitivity to immediacy estimates for signalled and unsignalled conditions, respectively, for each subject in the independent-scheduling group are as follows: Pigeon 185: 0.75 and 2.56; Pigeon 186: 2.90 and 3.97; Pigeon 187: 0.76 and 1.93; Pigeon 188: 2.27 and 2.78. Thus, for all subjects in the independent-scheduling group sensitivity to immediacy was also lower in the signalled conditions compared to the unsignalled conditions.

Corresponding data for the interdependent-scheduling group (Pigeons 161 to 164) are shown in Figures 5.3 and 5.4. Figure 5.3 shows the log initial-link response ratio as a function of the log probability ratio in the unsignalled conditions for the four subjects in the interdependent-scheduling group. As is evident in Figure 5.3, all subjects displayed high levels of sensitivity to relative probability in all components when the terminal links were unsignalled. Furthermore, sensitivity values were comparable across components. Individual sensitivity values, averaged across components, were 1.75, 2.19, 2.46 and 1.70, for Pigeons 161, 162, 163 and 164, respectively, with an overall average value of 2.03.

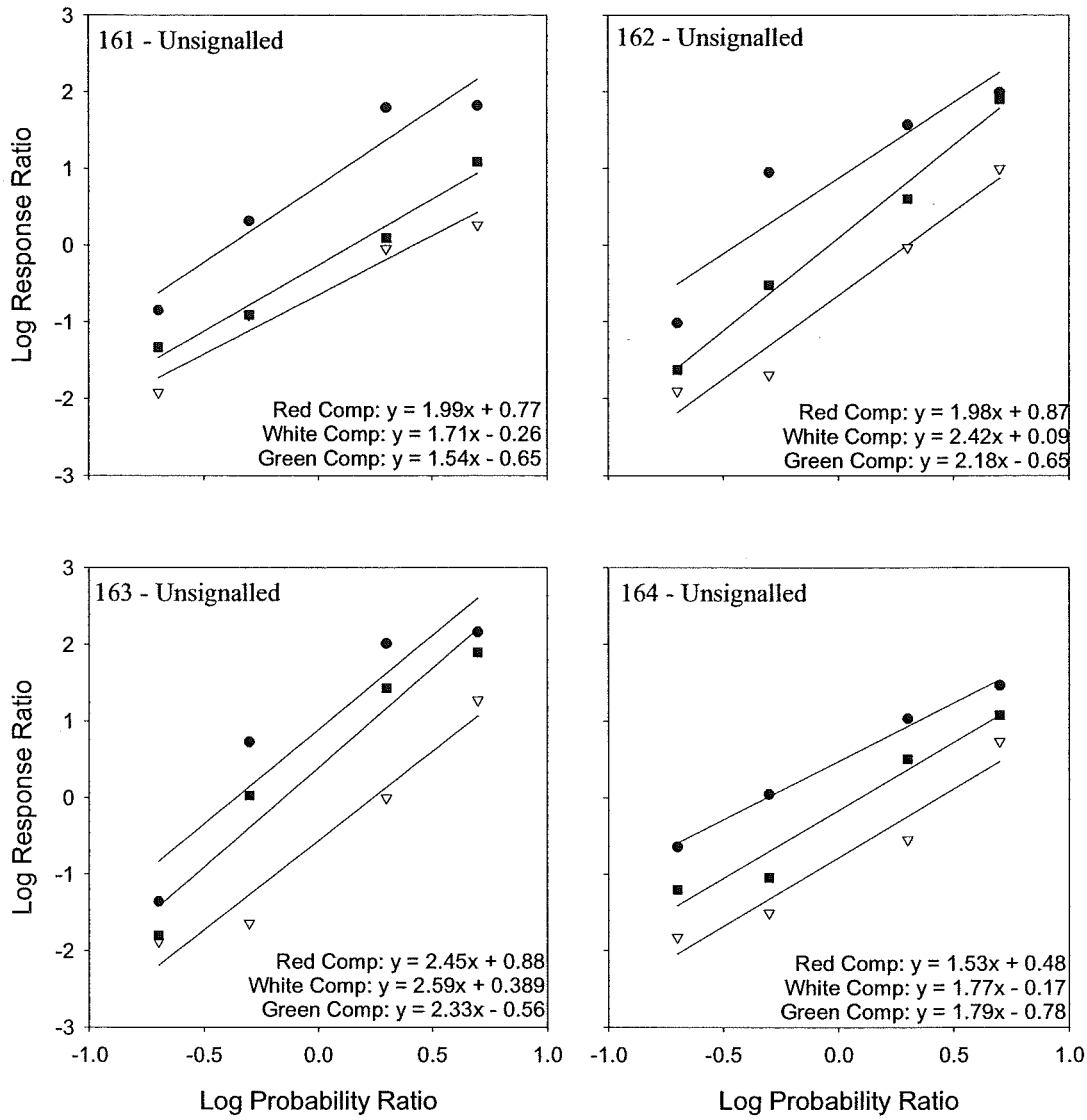

Figure 5.3: Log initial-link response ratios are plotted against log probability ratios in the unsignalled conditions, for subjects in the interdependent-scheduling group. GML equations are shown for each subject for the red, white and green components, respectively. Filled circles represent red components, filled squares represent white components and open triangles represent green components.

Figure 5.4 shows the log initial-link response ratio as a function of the log probability ratio in the signalled conditions for the same four subjects in the interdependent scheduling group. Response allocation for all subjects was sensitive to relative probability in each component when the terminal links were signalled. Again, sensitivity values were comparable across components. Individual sensitivity values averaged across components were 1.28, 1.23, 1.71 and 1.48, for Pigeons 161, 162,

163 and 164, respectively, with an overall average value of 1.42. The most important feature to notice here is that the sensitivity values are substantially lower in the signalled conditions relative to the unsignalled conditions. Sensitivity values for all subjects and components were lower in the signalled conditions than in the unsignalled conditions. Thus, for all 12 individual comparisons, sensitivity values in signalled components were lower than in unsignalled components. This means that sensitivity to relative probability was reduced in the signalled relative to the unsignalled conditions. Specifically the overall average sensitivity value in the unsignalled conditions was 2.03 compared with 1.42 in the signalled conditions. This confirms the signalling effect, whereby a reduced sensitivity to reinforcer probability is found when terminal-link reinforcement and extinction outcomes are signalled.

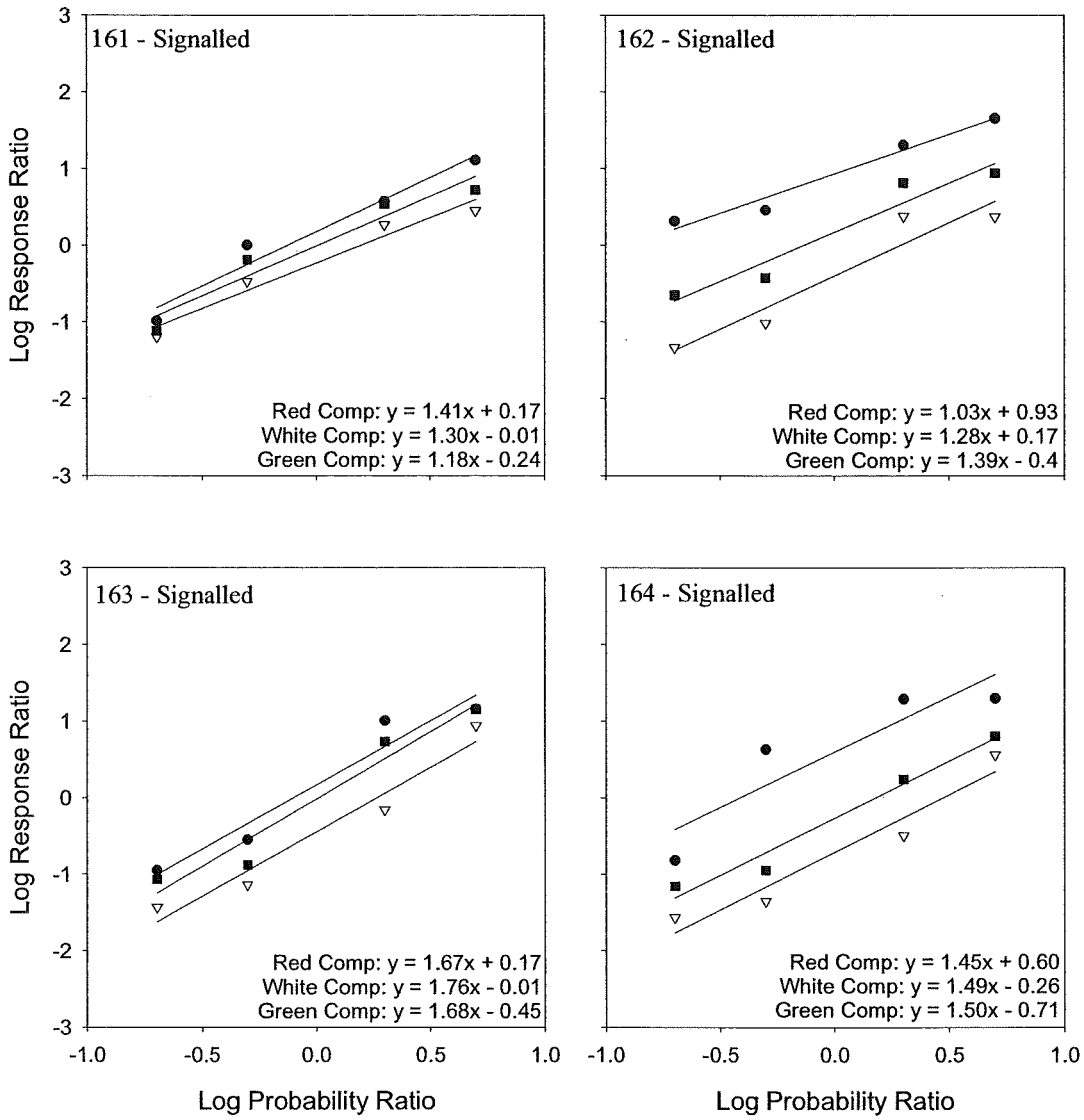

Figure 5.4: Log initial-link response ratios are plotted against log probability ratios in the signalled conditions, for subjects in the interdependent-scheduling group. GML equations are shown for each subject for the red, white and green components, respectively. Filled circles represent red components, filled squares represent white components and open triangles represent green components.

Evidence for sensitivity to immediacy is shown by the differential bias parameters across components. In the red component, all subjects showed a strong bias towards the left alternative (positive value for *b* with the shorter delay on the left), in green components subjects showed a strong bias towards the right alternative (negative value for *b* with the shorter delay on the right) and in white components there was no systematic bias (equal delays on both alternatives). Sensitivity to

relative reinforcer immediacy was also computed for the interdependent-scheduling group. The individual sensitivity to immediacy estimates for the signalled and unsignalled conditions, respectively, for each subject in the interdependent-scheduling group were as follows: Pigeon 161: 0.68 and 2.54; Pigeon 162: 2.21 and 2.54; Pigeon 163: 1.02 and 2.41; Pigeon 164: 2.18 and 2.09 (Pigeon 164 showed no significant difference). Thus, for three out of four subjects in this group the sensitivity estimate to relative reinforcer immediacy was lower in the signalled conditions relative to the unsignalled conditions, whereas for one subject (164) sensitivity to immediacy was approximately equal across both sets of conditions.

Group-mean data are presented in Figure 5.5. The left-hand panels show data from the unsignalled conditions and the right-hand panels show data from the signalled conditions. Data from the independent group are shown in the upper panels; corresponding data for the interdependent group are shown in the lower panels. As Figure 5.5 shows, for both groups initial-link response allocation was more sensitive to both reinforcer probability and immediacy when the terminal-link outcomes were unsignalled. Sensitivity to reinforcer probability is measured as the regression slopes; sensitivity to immediacy is measured as the difference between intercepts in the red and green components (divided by 2*log2). The average sensitivity to relative probability across components in the unsignalled conditions for the independent scheduling group was 1.88. Preferences were somewhat less sensitive to relative probability in the signalled conditions; the sensitivity estimate was reduced to 1.31. For the interdependent-scheduling group, sensitivity to relative probability in the unsignalled conditions was 2.03, and 1.42 in the signalled conditions. In summary, for six out of eight subjects the signalling effect was shown in all three components,

where there was greater sensitivity to relative probability is shown in the unsignalled conditions relative to the signalled conditions.

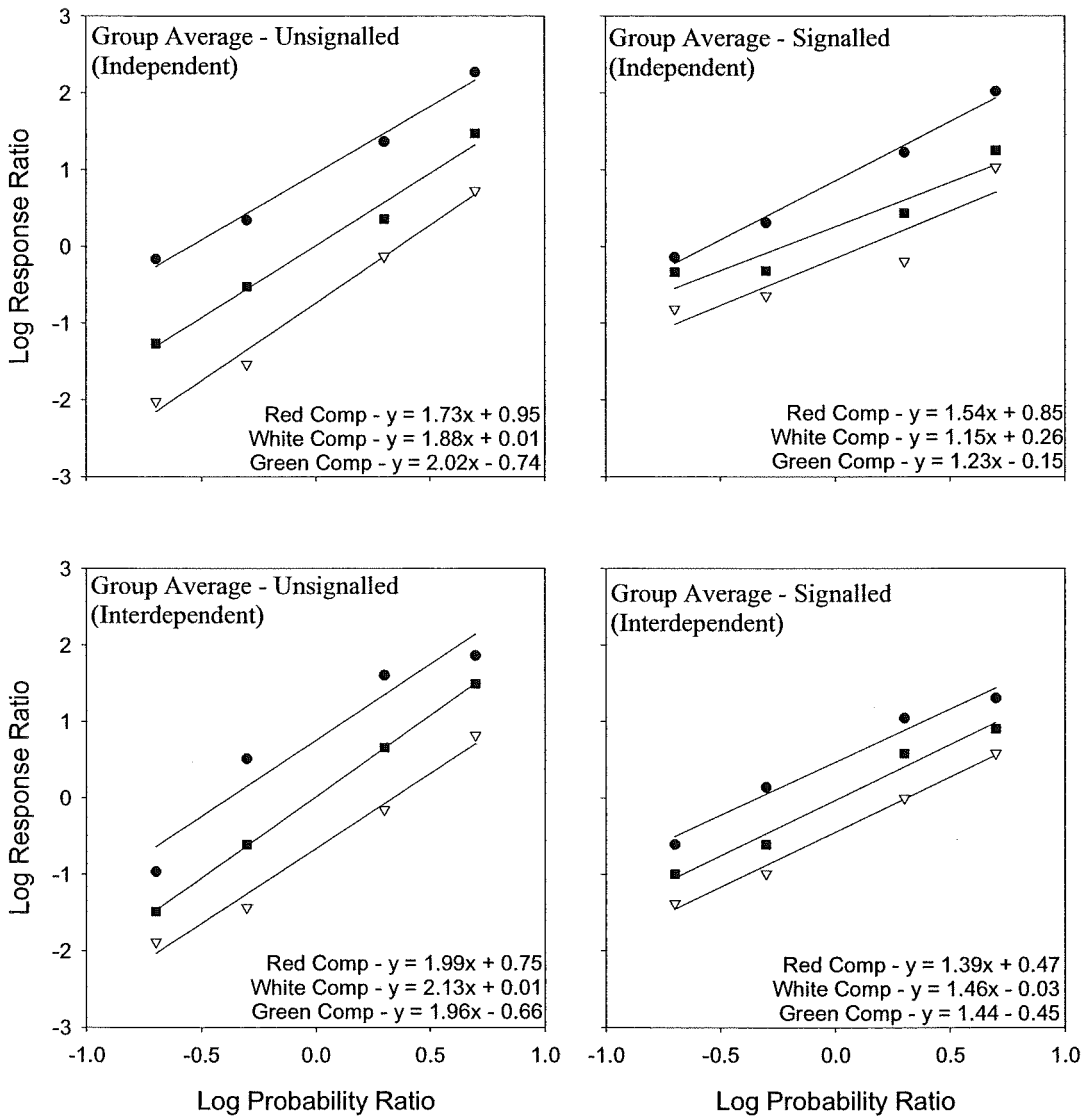

Figure 5.5: Group mean log initial-link response ratios from both groups are plotted against log probability ratios for both unsignalled and signalled conditions. The equations are also shown for each series. Filled circles represent red components, filled squares represent white components and open triangles represent green components.

Figure 5.5 also shows that the regression slopes are approximately parallel across components. Parallelism suggests that relative probability and relative immediacy of reinforcement have additive and independent effects on response allocation. Several analyses were conducted to quantify the deviation from independence by measuring the goodness of fit of the generalised matching law (Equation 5.3) to the data, assuming either a single value of a_p for all three components (single-slope model), or separate values of a_p for each component (multiple-slope model). If effects of probability and immediacy are independent, then the increase in variance accounted for when separate values of a_p are used for each component will not be significant.

Parameter estimates were obtained for the single- and multiple-exponent models that maximised the variance accounted for in the data. Models were fitted separately to the data from signalled and unsignalled conditions, and results are presented in Tables 5.3 and 5.4, respectively. For all subjects, in both signalled and unsignalled conditions, the improvement in variance accounted for by the multiple value model was very small. The largest increase was for Subject 185 (in signalled conditions) with 0.04 variance accounted for. All F ratios, computed to test whether the incremental variance was greater than zero, failed to reach significance. Overall, this analysis suggests that relative probability and immediacy have independent effects on initial-link response allocation.

Table 5.3: The results of model comparison for signalled conditions, with estimated parameter values and variance accounted for by the single-value model (b, ad, ap, VACs) and the multiple-value model (bm, ads, apr, apg, apw, VACm). Also shown are the *F* ratios on the incremental variance accounted for by the multiple-slopes model.

Bird	b	ad	ap	VACs		bm	ads	apr	apg	apw	VACm		F
161	0.94	0.68	1.30	0.95		0.94	0.68	1.41	1.18	1.30	0.95		0.29
162	1.71	2.20	1.24	0.95		1.71	2.20	1.03	1.39	1.28	0.96		0.59
163	0.81	1.00	1.71	0.95		0.81	1.00	1.69	1.69	1.76	0.95		0.02
164	0.68	2.37	1.39	0.94		0.68	2.43	1.45	1.21	1.49	0.94		0.21
185	1.36	0.59	0.61	0.93		1.36	0.59	0.83	0.46	0.54	0.97		3.53
186	1.20	1.73	0.84	0.98		1.20	1.73	1.02	0.66	0.85	0.98		1.08
187	1.59	0.99	1.01	0.95		1.59	0.99	1.06	0.95	1.01	0.95		0.03
188	2.47	1.29	0.98	0.96		2.47	1.29	0.80	1.14	0.99	0.97		0.49

Table 5.4: The results of model comparison for unsignalled conditions, with estimated parameter values and variance accounted for by the single-value model (b, ad, ap, VACs) and the multiple-value model (bm, adu, apr, apg, apw, VACm). Also shown are the *F* ratios on the incremental variance accounted for by the multiple-slopes model.

Bird	b	ad	ap	VACs		bm	adu	apr	apg	apw	VACm		F
161	0.91	2.38	1.75	0.94		0.91	2.38	2.01	1.53	1.70	0.95		0.50
162	1.27	2.52	2.20	0.95		1.27	2.52	1.99	2.18	2.43	0.95		0.31
163	1.73	2.41	2.46	0.93		1.73	2.41	2.47	2.33	2.59	0.93		0.07
164	0.69	2.09	1.70	0.96		0.69	2.09	1.54	1.79	1.78	0.97		0.33
185	1.15	1.37	1.02	0.98		1.15	1.37	1.18	0.79	1.09	0.98		0.97
186	1.20	1.96	1.19	0.95		1.20	1.96	1.13	0.83	1.61	0.97		0.97
187	1.51	1.35	1.24	0.97		1.51	1.35	0.99	1.49	1.25	0.98		1.84
188	1.28	1.86	1.24	0.98		1.28	1.86	1.02	1.45	1.24	0.98		1.15

Although the programmed terminal-link entry frequencies were equal for the independent initial-link group, the obtained entries could be unequal, especially for components in which response allocation was extreme. In the results reported above, any effect of unequal entries on response allocation was (possibly) confounded with effects of probability and immediacy. Thus, several additional analyses were conducted to determine whether the greater sensitivity to probability and immediacy in the unsignalled conditions, and the independent effects of probability and immediacy in both signalled and unsignalled conditions – were obtained regardless of the sensitivity to relative entry frequency (a_r).

On occasion, as preference becomes more extreme, relative entry rate may favour the richer alternative, creating a feedback relation between response allocation and relative entry frequency. Thus, although it would be simple to find the best-fitting value of a_r for this model comparison, the effect on unequal terminal-link entry may be confounded within the results. Thus, for a range of a_r values, to assess the effect of unequal terminal-link entry, analyses were conducted on the data from the independent group, where a_r was allowed to vary within that range. As preference was more extreme in the unsignalled conditions, there was necessarily a value of a_r for which the signalling effect would disappear. Therefore, the goal of this next analysis was to determine whether that point occurred within the typical range of a_r values. The same model-comparison analyses as above were conducted. However for this analysis, a step-wise transformation of the a_r value was used, with equally log-spaced units between 0.5 and 2. A step-wise transformation was used to enable assessment of changes in sensitivity to reinforcement variables at each level of a_r.

Overall, there was little change in variance accounted for by allowing a_r to vary. The largest improvement was Pigeon 187, with 0.01. Thus, at most, the improvement in variance accounted for was 1.3%. Of note, the signalling effect (greater sensitivity in unsignalled relative to signalled conditions) remained for all subjects as the value of a_r varied up approximately 1.3. However, for greater values of a_r, sensitivity to relative reinforcement in signalled and unsignalled conditions became more similar. That is, at greater values of a_r, sensitivity to relative reinforcement in signalled conditions was equal to or greater than sensitivity in unsignalled conditions. This occurred for three out of the four birds; specifically, when a_r was approximately equal to 1.8, 1.3, and 1.5 for Pigeons 185, 186, and 187, respectively. Sensitivity to relative reinforcement for Pigeon 188 remained stronger in unsignalled conditions at all values of a_r. However, these values fall outside of the normal range obtained for a_r (0.8 to1.0; Berg & Grace, 2004). It is unlikely that the value of a_r would normally be as high as those used in this analysis. Therefore, this analysis suggests that the impact of a_r is minimal, and does not systematically affect the magnitude of the signalling effect.

5.4: DISCUSSION

The primary purpose of this study was to investigate the effects on choice of varying parametrically relative probability and relative immediacy of reinforcement in a signalled concurrent-chains procedure. Pigeons responded in a three-component concurrent chains procedure, with either signalled or unsignalled terminal links. Across components, terminal-link durations were varied to yield immediacy ratios of 1:2, 1:1 and 2:1. Relative probability of reinforcement was varied across conditions

to yield probability ratios of 1:5, 1:2, 2:1 and 5:1. Generalised-matching analysis revealed a strong signalling effect. Specifically, a reduced sensitivity to relative probability in signalled relative to unsignalled conditions was obtained. Furthermore, this analysis revealed a reduction in sensitivity to relative immediacy. Overall, analyses indicated that not only was sensitivity to relative probability of reinforcement reduced, but that sensitivity to relative immediacy was also reduced by signalling in the terminal links. Thus, signalling availability of reinforcement in the terminal links has a more global effect on preference than first thought.

It may be helpful to summarise the model-comparison analyses. First, analyses were conducted to establish whether assuming multiple values for sensitivity to relative probability for each of the three components would account for more variance in initial-link response allocation than a single value. If not, independence of relative probability and immediacy of reinforcement would be supported. This analysis revealed that there was little difference between the models assuming a single value and one that assumed multiple values. Thus, it was concluded that relative probability and immediacy of reinforcement did indeed have independent effects on response allocation.

Secondly, the issue regarding unequal terminal-link entry rates for one group of subjects (independent initial-link scheduling) was investigated by allowing sensitivity to terminal-link entry (a_r) to vary. If this variation of a_r had no systematic effect, then it seems that the model comparison (with a_r set to one) was appropriate and without the possible confounding influence of changing sensitivity to unequal terminal-link entry. The results showed that changing the variable a_r did not

systematically affect sensitivity to other reinforcing variables, with all main effects still present as it varied within the normal range.

Further generalised-matching analyses were conducted using relative immediacy of reinforcement as the independent variable rather than relative probability of reinforcement. This analysis enabled further examination of the independence of relative variables of reinforcement. It revealed, as expected, that relative immediacy and probability of reinforcement had independent effects on preference, in both signalled and unsignalled conditions.

Previous research has shown that strong preference is established for the alternative offering the greater probability of reinforcement in standard unsignalled procedures (e.g., Fantino, Dunn & Meck, 1979; Spetch & Dunn, 1987). However, when reinforcement outcomes are signalled, this preference can sometimes reverse, so that greater preference is shown for the alternative offering a lower probability of reinforcement (Dunn & Spetch, 1990; Kendall, 1974, 1985). This reversal has been found to be more common in procedures with short initial links and long terminal links (Dunn & Spetch, 1990; Kendall, 1985). The current results are consistent with this previous research, in that greater preference was found in unsignalled conditions and reduced preference, in signalled conditions. As a parametric variation of reinforcer probability and immediacy in a signalled procedure had not previously been conducted it is difficult to directly compare results of prior studies. However, it may be appropriate to turn to the models or theories that attempt to explain results such as these. Models that view terminal-link stimuli as conditioned reinforcers

(stimuli acquire reinforcing strength by association with primary reinforcement) have been popular and successful when applied to signalled procedures.

The Delay Reduction Hypothesis (DRH; Fantino, 1969; Squires & Fantino, 1971) is one such model that has received support. It assumes that initial-link response rate (preference) would match relative value of the terminal links. The value of the terminal links is determined by all dimensions of primary reinforcement, i.e., immediacy and probability, and by any secondary reinforcement, i.e., terminal-link stimuli. According to Fantino, terminal-link stimuli acquire conditioned reinforcement strength in experimental contexts where the stimulus is correlated with a reduction in the average time to the primary reinforcer.

More recently, Dunn and Spetch (1990) have applied DRH to data from signalled percentage-reinforcement procedures. They suggested that the function of the terminal-link stimuli in signalled procedures is to bring reinforcement forward in time, because the outcome is signalled at the beginning of the terminal link. By signalling at the beginning of the terminal link, it is effectively shortened. However, stimuli presented in the reliable alternative are actually redundant because they always signal reinforcement due after the same delay. Thus, the stimuli do not acquire any additional conditioned-reinforcement value. Conversely, stimuli correlated with reinforcement in the unreliable alternative do function as conditioned reinforcers because they signal that reinforcement is forthcoming. Therefore in the unreliable alternative, entry to a terminal link that will end in reinforcement results in immediate conditioned reinforcement. Choice is then determined by weighing up certain primary reinforcement on one alternative against uncertain primary

reinforcement combined with immediate conditioned reinforcement on the other alternative. Preference is swayed towards the more immediate (conditioned) reinforcer. In signalled conditions, this results in a reduced preference for the certain alternative. In the current experiment, preference was stronger in conditions where the stimuli were not correlated with the eventual outcome (unsignalled), and was reduced in conditions where the stimuli were correlated with the eventual outcome (signalled). Therefore, these results are consistent with Dunn and Spetch's interpretation of DRH. Furthermore, if the function of the terminal-link stimuli is to bring forward the reinforcement outcome in time and effectively shorten the terminal link, it is not surprising that preference for the certain alternative is reduced because we know that preference is often reduced with shorter terminal links (MacEwen, 1972). Dunn and Spetch suggested that a combination of conditioned-reinforcement value on the unreliable alternative and a 'shorter' terminal link on that alternative caused the reduced preference for the reliable alternative in signalled conditions.

In summary, the data analysis has revealed that signalling whether or not reinforcement is forthcoming, has a global effect on terminal-link value and affects sensitivity to both varied dimensions of reinforcement, reinforcer probability and immediacy. Analyses also revealed that these variables of reinforcement have independent effects on behaviour, in both signalled and unsignalled conditions. Another experiment was conducted to investigate reinforcer magnitude and probability further. Specifically, in an experiment similar to the present experiment, we investigated the effects on preference of signalling relative probability of reinforcement, while also varying reinforcer magnitude.

CHAPTER 6: EXPERIMENT 5

Signalled and Unsignalled Terminal Links in Concurrent Chains: II. Effects of Reinforcer Probability and Magnitude

6.1: INTRODUCTION

This experiment is similar to that described in the previous chapter. In that experiment, reinforcer probability and immediacy were parametrically varied under both signalled and unsignalled terminal-link conditions. Pigeons responded in a three-component concurrent-chains procedure, where across components the relative immediacy of reinforcement was manipulated, and the relative probability of reinforcement was manipulated across conditions. In some conditions, the terminal-link stimuli were correlated with the eventual outcome (i.e., different stimuli were presented for the reinforcement and extinction outcomes). In other conditions, the terminal-link stimuli were not correlated with the outcome. Data supported the signalling effect: i.e., a reduced preference for the more reliable alternative in signalled relative to unsignalled conditions. Furthermore, sensitivity to relative immediacy of reinforcement was also reduced in signalled conditions. This second finding in particular is important because it suggests that when signals indicate whether or not reinforcement is due, they may have a global effect on sensitivity to all terminal-link contingencies.

Similarly, the current experiment investigates the effect on choice of parametrically varying reinforcer probability, but in combination with variation in reinforcer magnitude (instead of reinforcer immediacy). Pigeons responded in a similar procedure, where reinforcer magnitude was varied across components and reinforcer probability was varied over conditions. In some conditions (signalled) the terminal-link stimuli were correlated with the reinforcement outcome and in others (unsignalled) they were not correlated.

The probability of reinforcement is varied using different percentages of trials ending in reinforcement, and this may be varied independently of variation in relative reinforcer magnitude. As in the previous experiment, the terminal-link stimuli were either correlated (signalled) or uncorrelated (unsignalled) with the eventual outcome. The major aim of the current study was to investigate the signalling effect while simultaneously varying both the probability and magnitude of reinforcement offered by each alternative. This was done using a three-component concurrent-chains procedure, similar to Experiment 4 in the previous chapter. The major difference was that the terminal-link schedules were equivalent in each alternative, however the magnitude of reinforcement delivered at the end of each terminal link varied across alternatives. The initial-link schedules were constant across components and conditions (as in Experiment 4). Terminal-link schedules differed from Experiment 4, where currently they were always Fixed Time (FT) 15 s. Components were distinguished by the colour used for all stimuli (red, green, white). In the red component, the reinforcer magnitudes were 4 s 2 s, in the green component the reinforcer magnitudes were 2 s 4 s, and in the white component the reinforcer magnitudes were 3 s 3 s. The remaining features of Experiment 5 were equivalent to

those in Experiment 4. Thus, the design also allows examination of the effects on choice of parametric variation in relative reinforcer probability at different levels of relative magnitude, for both signalled and unsignalled terminal links.

6.2: METHOD

6.2.1: Subjects

Eight mixed breed pigeons, numbered 165 to 168 and 195 to 198, served as subjects. They were maintained at 85% of free-feeding body weights (± 15g) by post-session feeding when necessary. They were housed individually in a vivarium with a 12:12 hr light/dark cycle (lights on at 0700h), and with free access to grit and water. All had previous experience with a variety of experimental procedures.

6.2.2: Apparatus and Procedure

The Apparatus and Procedure were the same as in Experiment 4.

6.2.3: Concurrent Chains. Different pairs of terminal-link reinforcer magnitudes were used for each component, 4 s 2 s in the Red component; 2 s 4 s in the Green component; and 3 s 3 s in the White component, producing magnitude ratios of 2:1, 1:2, and 1:1. These remained unchanged throughout the experiment. The same pair of reinforcer probabilities was used across components in each condition, either 67%

33%; 33% 67%; 83% 17% or 17% 83%, producing ratios of 2:1, 1:2, 5:1, and 1:5. Probabilities were implemented by selecting from a list without replacement such that out of every 12 terminal links, reinforcement would be delivered ten times when the probability was 83%, eight times when it was 67%, four times when it was 33%, and two times when it was 17%. The four probability ratios were varied across eight conditions.

Table 6.1 lists the conditions, including the components and their associated magnitudes and probabilities, and whether or not the condition was signalled. These components involved either signalled or unsignalled terminal links. In the unsignalled conditions, the stimulus (flashing keylight) was the same for each occurrence of a particular terminal link, regardless whether food or blackout occurred on that trial. In the signalled conditions, a flashing houselight (0.25 s on, 0.25 s off) flashed in synchrony with the key light in each terminal link that ended in blackout. The order of conditions was counterbalanced across subjects. Thus, each subject began the experiment in a condition associated with a different probability ratio. Half the subjects experienced the four signalled conditions first and the other half experienced the four unsignalled conditions first.

Table 6.1: Conditions, terminal-link signalling (Y for signalled, N for not signalled) and their associated probabilities of reinforcement. The reinforcer magnitudes are shown for each component (Red, Green and White). Each terminal link is associated with Fixed Time (FT) 15 s delay.

		Red		**Green**		**White**	
Cond	Sig	4-s	2-s	2-s	4-s	3-s	3-s
1	Y	67%	33%	67%	33%	67%	33%
2	Y	33%	67%	33%	67%	33%	67%
3	Y	83%	17%	83%	17%	83%	17%
4	Y	17%	83%	17%	83%	17%	83%
5	N	67%	33%	67%	33%	67%	33%
6	N	33%	67%	33%	67%	33%	67%
7	N	83%	17%	83%	17%	83%	17%
8	N	17%	83%	17%	83%	17%	83%

As before, no formal stability criterion was employed and training in each condition continued for between 39 and 41 sessions, with one exception where training continued for 44 sessions. Table 6.2 lists the order of conditions and number of sessions of training for all subjects.

Table 6.2: Order of conditions for all subjects. Numbers of sessions is given in parentheses.

Pigeon	Cond	Pigeon	Cond	Pigeon	Cond	Pigeon	Cond
165	1 (39)	166	6 (39)	167	3 (39)	168	8 (39)
	2 (40)		5 (40)		4 (40)		7 (40)
	3 (40)		8 (40)		1 (40)		6 (40)
	4 (40)		7 (40)		2 (40)		5 (40)
	5 (40)		2 (40)		7 (40)		4 (40)
	6 (40)		1 (40)		8 (40)		3 (40)
	7 (40)		4 (40)		5 (40)		2 (40)
	8 (40)		3 (40)		6 (40)		1 (40)
195	1 (40)	196	6 (40)	197	3 (40)	198	8 (40)
	2 (44)		5 (44)		4 (44)		7 (44)
	3 (40)		8 (40)		1 (40)		6 (40)
	4 (41)		7 (41)		2 (41)		5 (41)
	5 (41)		2 (41)		7 (41)		4 (41)
	6 (41)		1 (41)		8 (41)		3 (41)
	7 (40)		4 (40)		5 (40)		2 (40)
	8 (40)		3 (40)		6 (40)		1 (40)

6.3: RESULTS

The analyses conducted in the current experiment are similar to those reported in the previous chapter. First, the analyses to test whether initial-link response allocation had stabilized at the end of each condition are reported. Next, generalised-matching analyses are described in which sensitivities to probability and magnitude,

in signalled and unsignalled conditions are examined. Finally, model-comparison analyses are reported to test whether probability and magnitude had independent effects on response allocation.

Because a formal criterion to determine if performance was stable prior to completing a condition was not used, several post-hoc stability analyses were conducted. First, for each component and condition, the log initial-link response ratios were regressed on session number across the last ten sessions. The sign of the log ratio was reversed for those conditions in which the reinforcement schedule was richer for the right alternative. Thus, for all conditions, positive slopes indicated that response allocation was becoming more extreme over the last ten sessions.

Overall, 96 slopes were computed across subjects, components and conditions, for each of the scheduling groups. In the independent-scheduling group, 48 of these were positive and 48 were negative (sign test, *ns*). The overall average slope across subjects was 0.0007. In the interdependent-scheduling group, 53 were positive and 43 were negative (sign test, *ns*). The overall average slope across subjects was 0.008. This suggests that across subjects and conditions, response allocation did not change systematically across the last ten sessions of training. The framework for analyses of sensitivity to reinforcer variables was the logarithmic version of the generalised matching law, including a term for relative probability:

The data were summed across the last ten sessions of each condition, for each component. As before, the raw or 'uncorrected' data were used in these analyses for the independent-scheduling group. Any effects of unequal terminal-link entries on

response allocation are confounded with variation in reinforcer probability and magnitude in these data. Analyses described below suggest that our results are robust to changes in sensitivity to entry rate; therefore in the model analyses described below, sensitivity to terminal-link entry was set to 1.

Figures 6.1 and 6.2 show data from the independent-scheduling group (Pigeons 185 to 188) in the unsignalled and signalled conditions, respectively. Figure 6.1 shows the log response ratio as a function of the log probability ratio in the unsignalled conditions for the four subjects in the independent-scheduling group. As is evident in Figure 6.1, all four subjects displayed high levels of sensitivity to relative probability, in all components when the terminal links were unsignalled. Individual sensitivity values averaged across components were 2.0, 2.60, 1.41 and 1.27, for Pigeons 195, 196, 197 and 198, respectively, with an overall average value of 1.82.

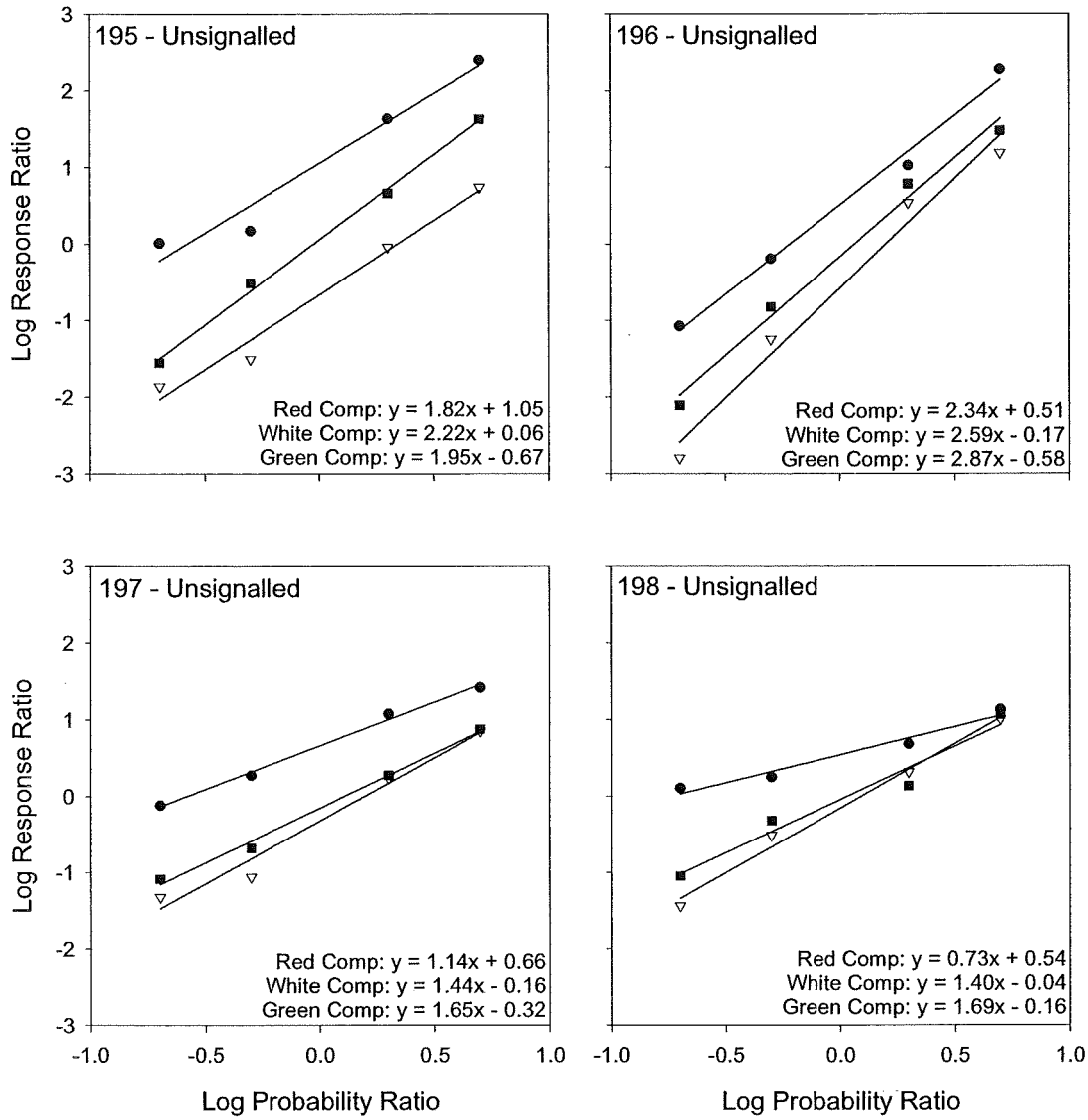

Figure 6.1: Log initial-link response ratios are plotted against log probability ratios in the unsignalled conditions, for subjects in the independent-scheduling group. GML equations are shown for each subject for the red, white and green components, respectively. Filled circles represent red components, filled squares represent white components and open triangles represent green components.

The sensitivity values obtained in the unsignalled conditions were higher than those obtained in the signalled conditions. Figure 6.2 shows the log response ratio as a function of the log probability ratio in the signalled conditions for the same four subjects in the independent scheduling group. There is a striking reduction in sensitivity to relative probability in signalled relative to unsignalled conditions (with the exception of Pigeon 197, discussed shortly). Individual sensitivity values

averaged across components were 0.53, 0.91, 2.14 and 1.18 for Pigeons 195, 196, 197 and 198, respectively, with an overall average value of 1.19. Overall, these results support the signalling effect.

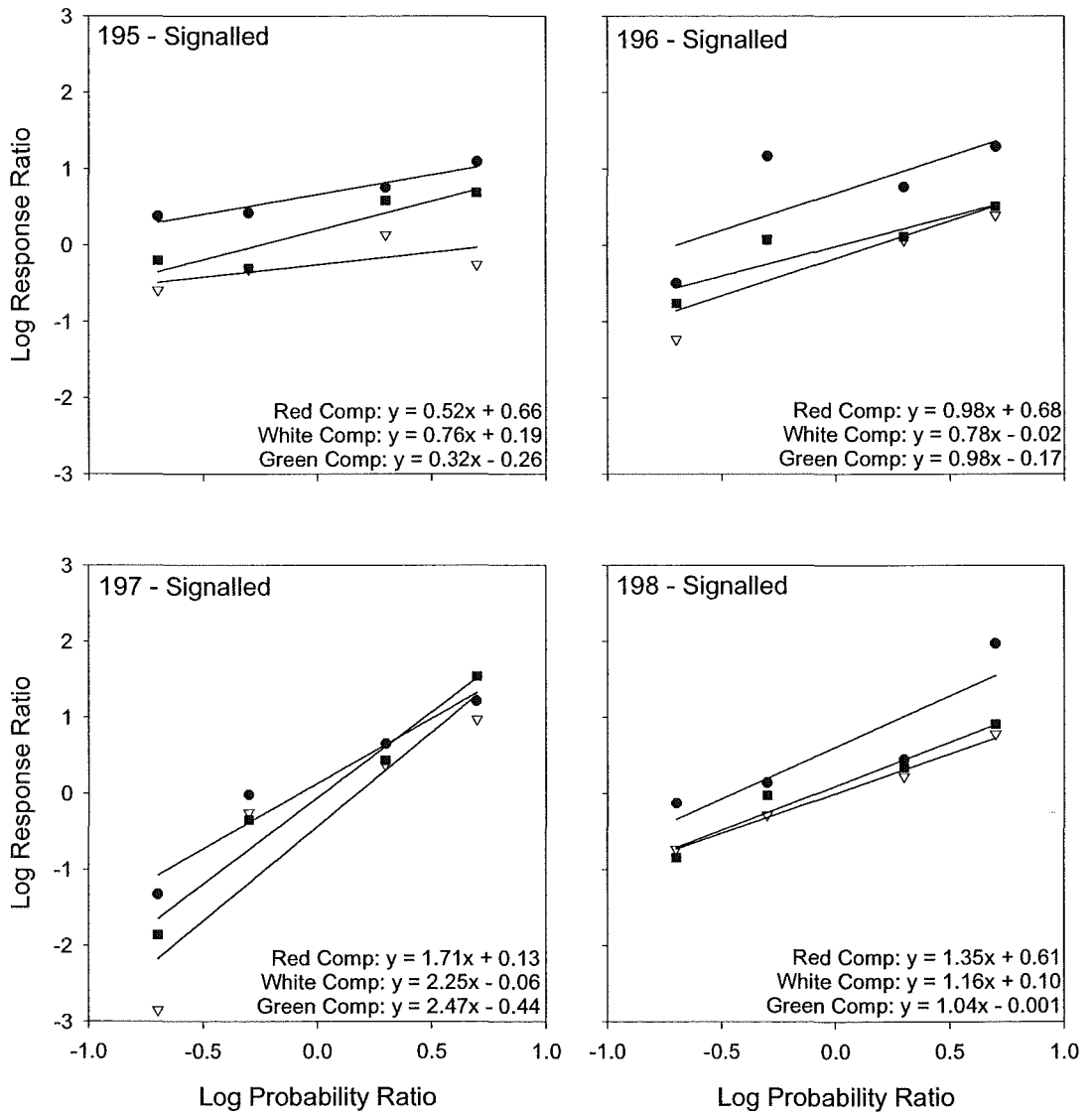

Figure 6.2: Log initial-link response ratios are plotted against log probability ratios in the signalled conditions, for subjects in the independent-scheduling group. GML equations are shown for each subject for the red, white and green components, respectively. Filled circles represent red components, filled squares represent white components and open triangles represent green components.

For one subject (Pigeon 197) the generalised-matching-law analyses showed more extreme preference and greater sensitivity in signalled conditions than in unsignalled conditions. When the data were corrected for unequal terminal-link entry (i.e., assuming that $a_r = 1.0$ in Equation 6.3), two out of three components showed greater sensitivity in the unsignalled conditions and data from the remaining component showed no difference between the two. This subject in particular had a very large discrepancy between terminal-link entry on the left and right alternatives in the 17% 83% signalled condition. It was entering and responding almost exclusively on the right alternative in the green component (largest magnitude on the right). In fact, it only entered the left terminal link twice in the last ten sessions and did not receive any reinforcers. In contrast, it entered the right terminal link 211 times during the same period. When this data point was removed from the original generalised matching analysis, the sensitivity values reversed so that sensitivity was greater in the unsignalled than in the signalled conditions. Thus, results for Pigeon 197 are not discrepant when the effects of unequal terminal-link entries are eliminated.

In the previous experiment, signalling probabilistic reinforcers was found also to affect sensitivity to relative immediacy. Examination of Figures 6.1 and 6.2 reveals the same effect of signalling on control by relative magnitude of reinforcement. This control is evidenced by the distances between regression lines: greater distance between lines represents greater control by the other reinforcement variable being manipulated. As is evident in the figures, there is greater distance between lines in the unsignalled conditions relative to that seen in the signalled conditions. This suggests that control by both relative probability and relative magnitude was stronger in unsignalled conditions. To obtain estimates of sensitivity to relative magnitude, the *y*-

intercept value of the regression equation for the green component was again subtracted from that for the red component, and divided by 2*log (2). The individual sensitivity to immediacy estimates for each subject for signalled and unsignalled conditions, respectively, were as follows: Pigeon 195: 1.53 and 2.86; Pigeon 196: 1.42 and 1.81; Pigeon 197: 0.95 and 1.64; Pigeon 198: 1.02 and 1.16. Thus, for all four birds in this group, sensitivity to relative magnitude was reduced in signalled conditions compared to unsignalled conditions.

Figure 6.3 shows the log response ratio as a function of the log probability ratio in the unsignalled conditions for the four subjects in the interdependent-scheduling group. High levels of sensitivity to relative probability were obtained for all subjects in the unsignalled conditions. These values were comparable across components. Individual sensitivity values averaged across components were 2.0, 2.15, 1.77 and 1.98, for Pigeons 165, 166, 167 and 168, respectively, with an overall average value of 1.98.

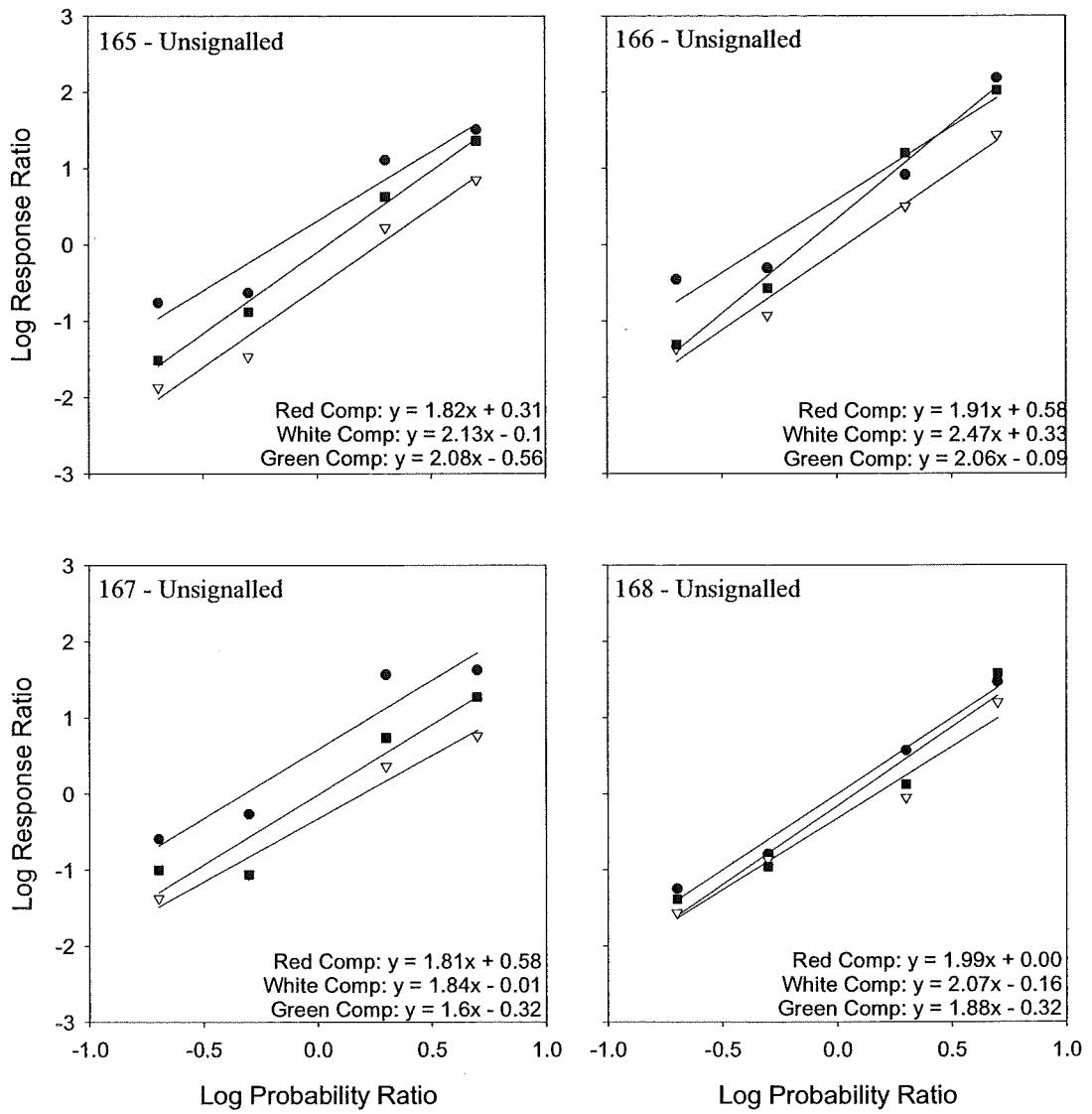

Figure 6.3: Log initial-link response ratios are plotted against log probability ratios in the unsignalled conditions, for subjects in the interdependent-scheduling group. GML equations are shown for each subject for the red, white and green components, respectively. Filled circles represent red components, filled squares represent white components and open triangles represent green components.

Figure 6.4 shows the log response ratio as a function of the log probability ratio in the signalled conditions for the same four subjects in the interdependent-scheduling group. Data showed that for all four subjects moderate sensitivity to relative probability was obtained in all components when the terminal links were signalled. Again, sensitivity values were generally comparable in the three components, except for Pigeon 166, who had lower sensitivity in the red component compared to the other components. Individual sensitivity values averaged across components were 1.04, 0.72, 0.82 and 1.07, for Pigeons 165, 166, 167 and 168, respectively, with an overall average value of 0.91. It is also clear that the slopes of the lines in Figure 6.4 are considerably flatter than those in Figure 6.3. All sensitivity values, across subjects and components, were lower in the signalled conditions than in the unsignalled conditions. This means that the degree of sensitivity to relative probability was greatly reduced in the signalled relative to the unsignalled conditions. Specifically the overall average sensitivity value in the unsignalled conditions was 1.98 compared with 0.91 in the signalled conditions. Again, these results support the signalling effect: reduced sensitivity to relative reinforcement was found in the unsignalled as opposed to signalled procedure.

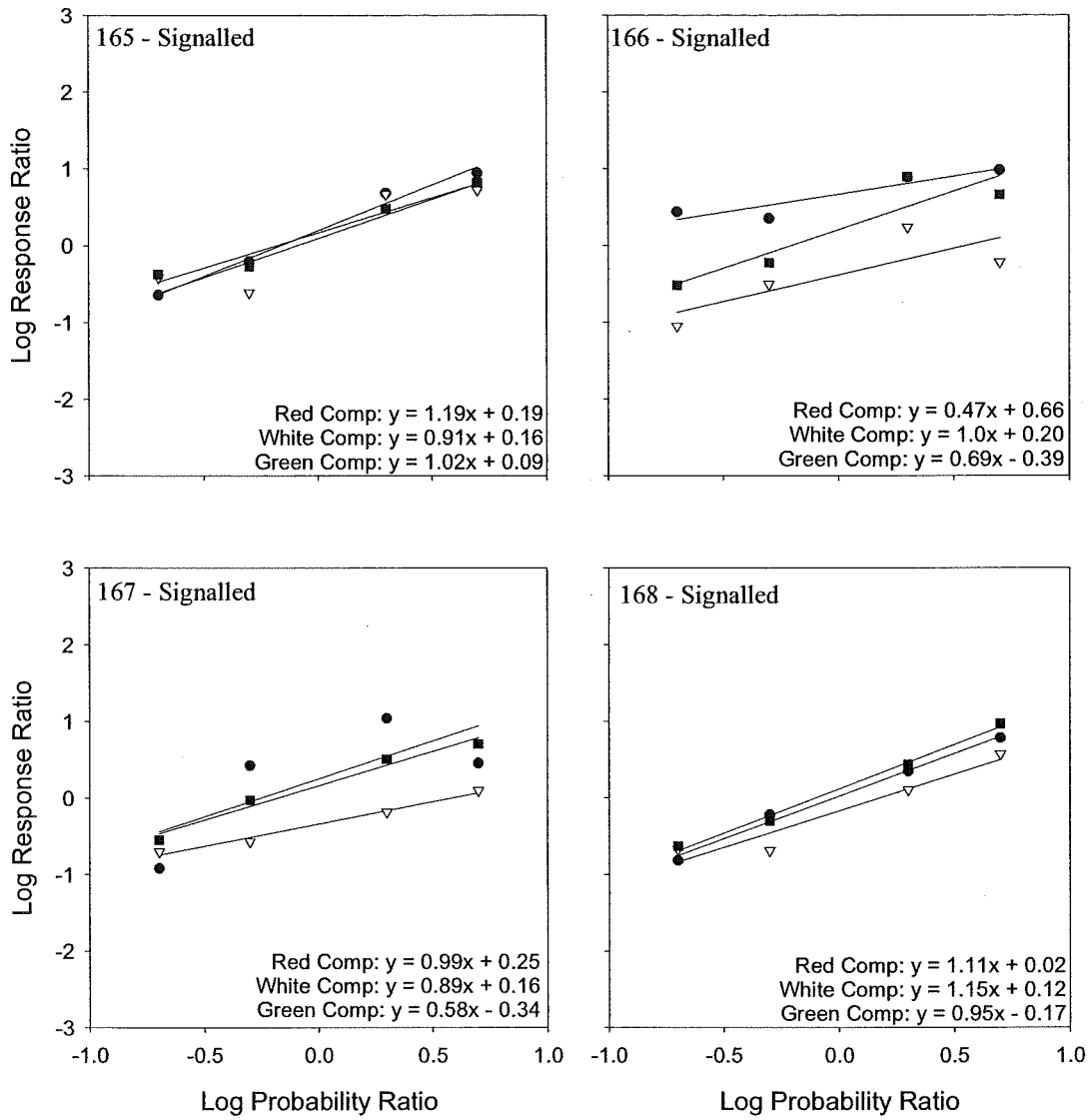

Figure 6.4: Log initial-link response ratios are plotted against log probability ratios in the signalled conditions, for subjects in the interdependent-scheduling group. GML equations are shown for each subject for the red, white and green components, respectively. Filled circles represent red components, filled squares represent white components and open triangles represent green components.

The same analysis of sensitivity to relative magnitude in signalled and unsignalled conditions was conducted for this group. The individual sensitivity estimates for signalled and unsignalled conditions respectively, are as follows: Pigeon 165: 0.17 and 1.45; Pigeon 166: 1.74 and 1.12; Pigeon 167: 0.98 and 1.51; Pigeon 168: 0.32 and 0.53. Thus, for three out of four birds in this group, sensitivity to relative magnitude was reduced in signalled relative to unsignalled conditions.

Overall, this effect was obtained for seven out of the eight subjects (Pigeon 166 was the exception), with greater sensitivity to magnitude in the unsignalled conditions relative to the signalled conditions. It is evident therefore that relative magnitude exerts greater control over response allocation in unsignalled conditions than in signalled conditions. That is, signalling has reduced control by both the primary (relative probability) and secondary (relative magnitude) independent variables.

Figure 6.5 shows group-average data from both scheduling groups. Panel A shows data from the unsignalled conditions and Panel B, data from the signalled conditions. It shows the log initial-link response ratio averaged across subjects as a function of the log probability ratio for all components and conditions. For all subjects, the response ratio was an increasing function of relative probability of reinforcement. Both signalled and unsignalled conditions produced high levels of preference. However, the most important aspect to note is the large reduction in sensitivity to relative probability in the signalled conditions, relative to the unsignalled conditions. As is evident, preference was highly sensitive to relative probability when the terminal-link outcomes were unsignalled. The average sensitivity across unsignalled conditions in the independent-scheduling group was 1.82. Preference was less sensitive to relative probability in the signalled conditions; the mean sensitivity estimate was reduced to 1.19. Results were similar with greater disparity between signalling conditions in the interdependent-scheduling group. The average sensitivity estimate in the unsignalled conditions was 1.98, which reduced to 0.91 in the signalled conditions.

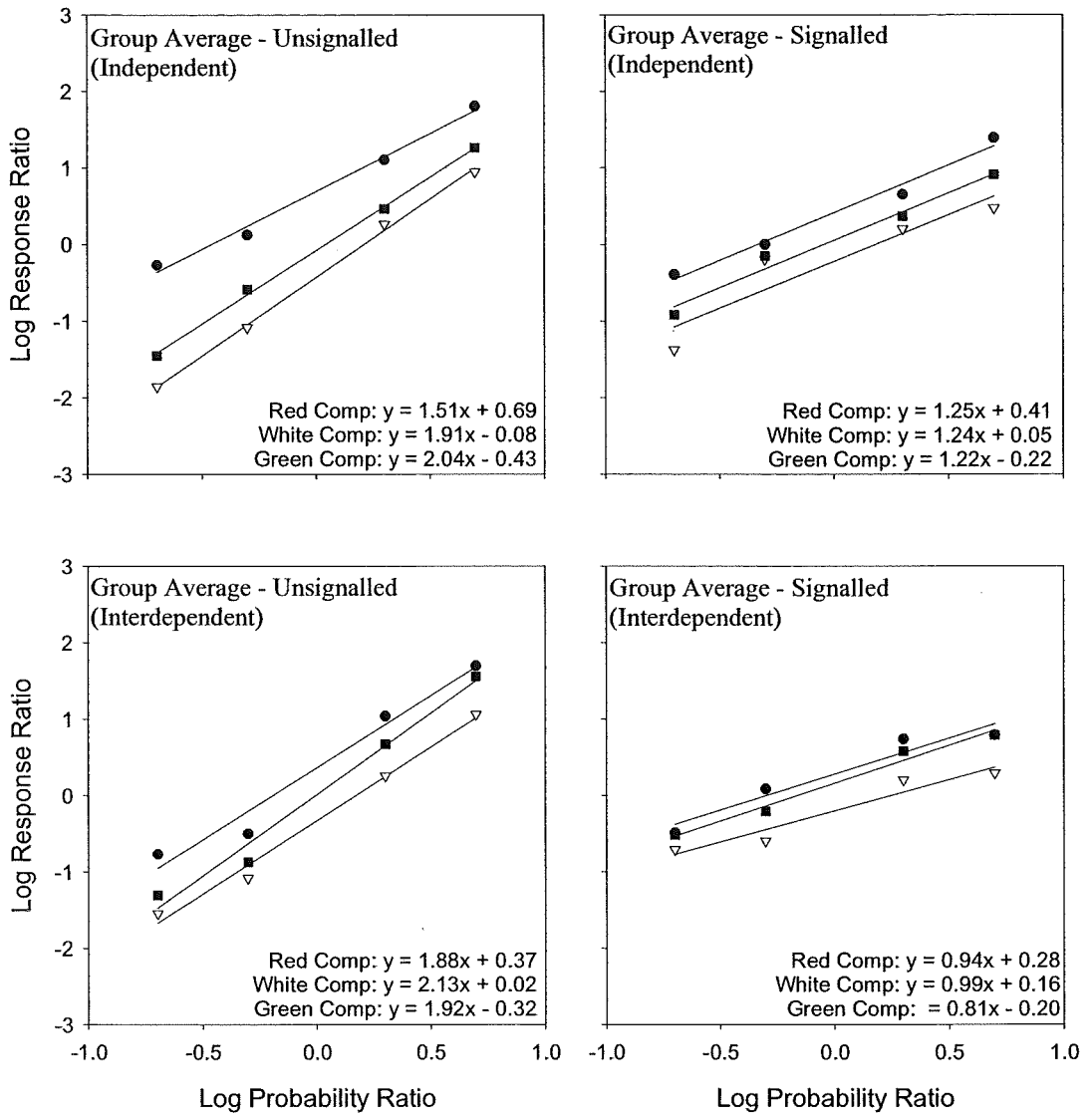

Figure 6.5: Group mean log initial-link response ratios from both groups are plotted against log probability ratios for both unsignalled and signalled conditions. The equations are also shown for each series. Filled circles represent red components, filled squares represent white components and open triangles represent green components.

In summary, for six out of the eight birds, the signalling effect was obtained in all three components. One subject (Pigeon 198) showed the effect in two out of three components: for only one component was sensitivity greater in the signalled conditions than in the unsignalled conditions. The other subject (Pigeon 197) was a counter example, where greater sensitivity was shown in signalled conditions in all

three components. However, as noted above, results for this subject were not discrepant when the effect of unequal terminal-link entries was taken into account.

In addition to the above analyses, several analyses were conducted to determine whether relative probability and magnitude of reinforcement had independent effects on response allocation. The independence analyses involved a comparison between a model with a single value for the parameter estimate of sensitivity to relative probability, versus a model with multiple values for this parameter. Specifically, in the multiple-value model, three values were estimated for sensitivity to probability, a_{pr}, a_{pg} and a_{pw} (one each for the red, green and white components). The sensitivity parameter for terminal-link entry rate (a_r) was held at 0; bias estimates are represented by b, and sensitivity to magnitude is represented by a_{ms} or a_{mu}, in the signalled or unsignalled conditions, respectively. Obtained initial-link response ratios and terminal-link entry rates were used for analysis. However, programmed reinforcement ratios were used, as on occasion subjects did not receive any reinforcement from one alternative during a component. Parameter estimates that maximised the variance accounted for by the single and multiple models were obtained, and are presented in Tables 6.3 and 6.4.

Table 6.3: The results of model comparison for signalled conditions, with estimated parameter values and variance accounted for by the single-value model (b, am, ap, VACs) and the multiple-value model (bm, ams, apr, apg, apw, VACm). Also shown are the F ratios on the incremental variance accounted for by the multiple-value model.

Bird	b	am	ap	VACs		bm	ams	apr	apg	apw	VACm		F
165	1.41	0.17	1.04	0.90		1.41	0.17	1.19	1.02	0.92	0.91		0.3714
166	1.44	1.74	0.72	0.84		1.44	1.74	0.47	0.69	1.00	0.88		0.8214
167	1.06	0.98	0.82	0.72		1.06	0.98	0.99	0.58	0.89	0.75		0.296
168	0.98	0.32	1.07	0.95		0.98	0.32	1.11	0.95	1.15	0.95		0.3743
195	1.44	1.34	0.45	0.90		1.44	1.34	0.41	0.28	0.67	0.93		1.2676
196	1.56	1.03	0.66	0.86		1.56	1.03	0.76	0.66	0.56	0.87		0.0846
197	0.98	0.30	1.03	0.98		0.98	0.30	0.90	1.01	1.18	0.99		0.5566
198	1.40	0.51	0.81	0.97		1.40	0.51	0.75	0.75	0.92	0.98		0.474

Table 6.4: The results of model comparison for unsignalled conditions, with estimated parameter values and variance accounted for by the single-value model (b, am, ap, VACs) and the multiple-value model (bm, amu, apr, apg, apw, VACm). Also shown are the F ratios on the incremental variance accounted for by the multiple-value model.

Bird	b	am	ap	VACs		bm	amu	apr	apg	apw	VACm		F
165	0.76	1.44	2.00	0.97		0.76	1.44	1.81	2.07	2.13	0.97		0.449
166	1.87	1.07	2.13	0.96		1.87	1.07	1.86	2.06	2.46	0.97		1.297
167	1.22	1.49	1.76	0.93		1.22	1.49	1.81	1.64	1.83	0.94		0.088
168	0.69	0.52	1.98	0.97		0.69	0.52	1.99	1.88	2.06	0.97		0.121
195	1.18	1.54	0.98	0.98		1.18	1.54	0.88	0.97	1.10	0.98		0.27
196	0.97	0.89	1.73	0.99		0.97	0.89	1.55	1.82	1.81	0.99		0.617
197	1.17	1.23	1.10	0.96		1.17	1.23	0.89	1.22	1.19	0.97		0.724
198	1.30	0.96	0.86	0.95		1.30	0.96	0.55	1.12	0.90	0.98		3.345

The largest increase in variance accounted for achieved by assuming multiple values for sensitivity to relative probability was 0.03 (Pigeon 166, signalled conditions). The overall averages in signalled conditions were 0.02 and 0.01 for the interdependent and independent groups, respectively. The overall averages in unsignalled conditions were 0.01 for both the interdependent and independent groups, respectively. *F* ratios were computed to test the incremental variance accounted for by the multiple value model and the increase was not significant. This analysis shows that there is little improvement by assuming multiple values for sensitivity parameters to relative probability, which in turn suggests that relative probability and relative magnitude have independent effects on response allocation.

It is possible that as response allocation becomes more extreme, relative terminal-link entry can favour the richer alternative, creating a feedback relationship. To assess the possibility that sensitivity to terminal-link entry has an impact on preference, further analyses were conducted with data from the independent-scheduling group. It may be that as a_r is increased, there will be some value for which sensitivities to reinforcer magnitude and probability are no longer greater in the unsignalled conditions. The aim of these analyses was to determine this value for each pigeon in the independent group. The value of a_r (sensitivity to relative terminal-link entry) was allowed to vary within a range of 0.5 to 2, instead of being set at 1 as in the previous analyses. A step-wise transformation of a_r was used, with equally log spaced units from 0.5 to 2. The largest improvement in variance accounted for when the value of a_r was allowed to vary, was 0.01 (Pigeon 198). The value of a_r for each subject for which sensitivities to reinforcer magnitude and probability were greater in signalled than in unsignalled conditions was then obtained.

For two subjects, Pigeons 197 and 198, sensitivity values failed to reverse up to values of a_r = 1.5 and 2.1, respectively. For Pigeon 195, sensitivity values reversed at a_r = 1.2; and for Pigeon 196, they reversed at a_r = 0.75. Thus, for one subject (Pigeon 196), the effect of unequal terminal-link entries may have been confounded with the signalling effect. However, for the other three subjects, there appears to be little effect on the magnitude of the signalling effect of changing values of a_r. Overall, the signalling effect (greater sensitivity to probability in unsignalled relative to signalled conditions) remained strong. Thus, independent scheduling of terminal-link entry does not appear to greatly affect response allocation.

6.4: DISCUSSION

This experiment investigated the effects of parametrically varying reinforcer probability and magnitude, in a signalled procedure. Subjects responded in a three-component concurrent-chains procedure. Across components, relative magnitude of reinforcement was varied, while across conditions relative probability of reinforcement was varied. Terminal-link stimuli were either correlated with the eventual outcome (signalled) or were uncorrelated (unsignalled). Thus, some conditions involved signalled terminal links and others involved unsignalled terminal links. Previous research has found strong preference for the richer alternative in unsignalled conditions, and a substantially reduced preference for the same alternative in signalled conditions. Data supported a strong signalling effect, where sensitivity to relative probability of reinforcement was greater in unsignalled than in signalled conditions. Specifically, generalised-matching analyses showed that sensitivity to relative probability was reduced when signals of reinforcement, to indicate whether or

not reinforcement would occur, were used in the terminal links. Furthermore, this analysis revealed that sensitivity to relative magnitude was also reduced in signalled compared to unsignalled conditions. This second effect was originally not expected because the signals were only informative as to whether reinforcement would occur, not its magnitude – however, it is consistent with results described in the previous chapter (Experiment 4). Further analyses revealed that the reductions in sensitivity to reinforcer probability and to reinforcer magnitude in signalled conditions were similar. This suggests that signalling affects all terminal-link reinforcing variables to the same extent. Overall, it appears that signalling has a more global effect on terminal-link value, and thus on preference, than first thought.

As in the previous experiment, analyses were conducted to assess the independence of reinforcer probability and magnitude. Generalised-matching analyses were conducted using relative magnitude of reinforcement as the independent variable rather than relative probability of reinforcement. This analysis revealed, as expected, that relative magnitude and probability of reinforcement had independent effects on preference, in both signalled and unsignalled conditions. Model-fitting analyses were conducted. The model that assumed either a single sensitivity (to reinforcer probability) parameter for all three components, or multiple parameters (one for each component) was used. If sensitivity to reinforcer probability was affected systematically by relative reinforcer magnitude, then different sensitivity parameters would result in a better fit of the model than a single value. The results of these fits showed that multiple parameters did not significantly improve the variance accounted for in initial-link response allocation. Thus, it appears that reinforcer probability and magnitude have independent effects on preference. This was not

known before this study as relatively few studies have varied both reinforcer probability and magnitude. In combination with the results from the previous study (Experiment 4) this provides support for the concatenated matching law as an adequate model of choice because each reinforcement variable had independent effects on choice.

Traditionally, theories of conditioned reinforcement have been applied to explain the effects of signalling in percentage-reinforcement procedures. According to this view, stimuli presented in the terminal link become conditioned reinforcers, acquiring reinforcing strength from their temporal association with primary reinforcement (Fantino, 1977). Consider the situation where one alternative has certain reinforcement, and the other has probabilistic (uncertain) reinforcement. On the uncertain alternative, stimuli presented during the terminal link differentially signal which outcome would accrue at the end of the delay (i.e., reinforcement or no reinforcement). According to a conditioned-reinforcement view, on occasions when reinforcement is signalled, the stimulus concerned acquires additional reinforcing strength. Thus, the alternative as a whole acquires added reinforcing value. The certain alternative, on the other hand, does not acquire any added value because the signals on that alternative are redundant (they always signal reinforcement). The most prominent model of conditioned reinforcement is the Delay Reduction Hypothesis (DRH; Fantino, 1969; Squires & Fantino, 1971), which posits that when stimuli signal a reduction in time to reinforcement an increase in reinforcing strength on that alternative occurs.

Because the current research investigated reinforcer magnitude and not delay, it is not obvious how to apply some models of conditioned reinforcement. One way to apply DRH is to consider that terminal-link stimuli associated with a reinforcement outcome signal a reduction in time to the *larger* reinforcer rather than to primary reinforcement *per se*. For example, one alternative might offer a fixed magnitude (i.e., 3 s) of reinforcement, while the other offers mixed magnitudes (i.e., 2 s or 4 s) of reinforcement with the same mean. On the mixed alternative in signalled conditions, one stimulus would be associated with the smaller reinforcer and another stimulus would be associated with the larger reinforcer. Therefore, on the mixed alternative, the terminal-link stimuli would signal the size of the reinforcer. The mixed alternative would therefore acquire additional conditioned reinforcing strength because of the stimulus that signals a reduction in time to the larger reinforcer. The stimuli on the fixed alternative do not acquire any conditioned reinforcing strength because they always signal the same size reinforcer. The value added by the stimuli in the mixed alternative may help shift preference towards that alternative, thus resulting in the signalling effect – reduced preference for the more reliable alternative in signalled relative to unsignalled conditions. In this way, the principles of DRH still apply when magnitude of reinforcement is varied instead of reinforcer immediacy.

CHAPTER 7: GENERAL DISCUSSION

7.1: Recap of the major findings of the present research

The aim of Experiment 1 was to replicate the signalling effect with probabilistic reinforcement, and to extend it by signalling different magnitudes of reinforcement. The question was would signalling which of two magnitudes will occur at the end of the terminal link have the same effect on preference as signalling whether or not reinforcement was due at the end of the terminal link?

In Experiment 1, in a percentage-reinforcement concurrent-chains procedure, pigeons were given the choice between two alternatives with identical-duration initial and terminal links. Choice of one alternative (uncertain) led to one of two possible outcomes, reinforcement (3.5 s) or blackout, with a probability of .5. Choice of the other alternative (certain) always resulted in food (3.5 s) at the end of the delay. When the scheduled outcome on the uncertain side was signalled, there was a moderate to strong preference for the certain side. When the scheduled outcome on the uncertain side was unsignalled, preference for the certain side became more extreme. This result replicates the signalling effect. With a similar design, another three conditions manipulated the magnitude of reinforcement, rather than its probability. When reinforcement on the uncertain alternative involved certain but different magnitudes, a weaker signalling effect was obtained. This experiment included reversal conditions. Unfortunately, the signalling effect was not obtained post-reversal. That the signalling effect was not robust across the reversal might

reduce confidence in the original finding. Thus, completing a replication of this experiment with a two-component procedure, with a condition and its reversal presented in different components within sessions might help make the effects more robust and facilitate experimental investigation.

The question remains, what is it about probabilistic reinforcement that might result in the reduced preference for the richer alternative in signalled conditions? There seems to be at least two reasons why subjects would prefer the certain (or richer) alternative in unsignalled conditions – the reinforcement is less variable and thus more predictable on the certain alternative, and the certain alternative has the greater expected magnitude of reinforcement. Firstly, probabilistic reinforcement is inherently variable, and because pigeons prefer fixed over variable magnitudes of reinforcement (Hamm & Shettleworth, 1987), signalling may act to reduce that preference for fixedness – resulting in more equal response allocation between the fixed and variable alternatives. Experiment 2 investigated this possibility.

Experiment 2 investigated the effects of relative variability on preference. In a similar design to Experiment 1, pigeons chose between alternatives that differed in terms of relative variability of reinforcement, while the relative expected magnitude of reinforcement was equal across alternatives. Fixed magnitudes of reinforcement, signalled variable magnitudes of reinforcement and unsignalled variable magnitudes of reinforcement as terminal-link outcomes were compared with one another. Data analysis suggested that the choices could be ranked in order of preference. Overall pigeons preferred fixed over unsignalled-mixed magnitudes. Fixed magnitudes of reinforcement were also preferred over signalled variable magnitudes, but by less

than unsignalled variable magnitudes. Signalled variable magnitudes were preferred over unsignalled variable magnitudes. Thus, reinforcement contingencies could be ranked in order of preference as follows: fixed, signalled mixed, unsignalled mixed. These results confirm our hypotheses that firstly, pigeons prefer fixed magnitudes and secondly, signalling reduces that preference.

A second reason why we could expect stronger preference for the more reliable alternative is that as expected magnitude of reinforcement is a powerful determiner of choice, signalling may act to reduce control by expected magnitude of reinforcement. Experiment 3 investigated this further. Experiment 3 assessed the effects on preference of signalling which of two magnitudes of reinforcement would occur at the end of the terminal link, while varying relative expected magnitude of reinforcement, and holding relative variability of reinforcement constant and equal across alternatives. Because Experiment 2 found better control of preference was obtained in conditions that were run successively, this experiment involved a two-component concurrent-chains procedure, with either signalled or unsignalled terminal links. One alternative delivered a greater expected magnitude of reinforcement than the other; it was assumed that preference would favour the alternative with the greater expected magnitude. It was hypothesised that choice would be less sensitive to relative expected magnitude in signalled than in the unsignalled condition. However, only a small reduction in preference was obtained. Overall, the results were inconclusive; three out of four subjects showed reduced sensitivity, however the fourth showed stronger sensitivity in the signalled than in the unsignalled condition. Unfortunately, with these results, the hypothesis (that signalling reduces sensitivity of behaviour to expected magnitude) can neither be supported nor rejected.

Two further experiments parametrically varied relative reinforcer probability and either relative delay or relative magnitude of reinforcement. How would signalling one dimension of reinforcement affect sensitivity to another dimension of reinforcement? Would signalling only affect sensitivity to reinforcer probability? If so, the independence assumption would be extended to situations in which probabilistic reinforcers were signalled. If not, it would suggest that signalling influences the relative value of terminal links, and affects the independent effects that various dimensions of reinforcement have on behaviour.

Experiments 4 and 5 both involved a three-component concurrent-chains procedure, in which relative probability of reinforcement was varied across conditions and relative immediacy (Experiment 4) or relative magnitude (Experiment 5) of reinforcement varied across components. In some conditions terminal-link stimuli were correlated with the outcome (signalled), and in others they were uncorrelated (unsignalled). The aim of these experiments was to study the effects on preference of signalling terminal-link outcomes that varied on more than one dimension of reinforcement. Would signalling whether or not reinforcement was forthcoming also have an effect on sensitivity of response allocation to other dimensions of reinforcement?

The signalling effect was replicated in both experiments: stronger preference for the richer alternative (greater probability of reinforcement) was obtained in the unsignalled relative to the signalled conditions. This effect was consistent across all except one subject – all eight subjects in Experiment 4 and seven subjects in Experiment 5. However, one counter example across all 16 subjects (both

Experiments 4 and 5) is not sufficient to undermine the conclusion that signalling whether or not reinforcement is forthcoming reduces preference for the richer alternative.

A further and possibly more interesting result from these two experiments was that signalling whether reinforcement was forthcoming (probability of reinforcement) also reduced sensitivity to relative immediacy (or relative magnitude in Experiment 5), the secondary independent variable. This result is particularly intriguing because the terminal-link signals only pertain to whether reinforcement is due, not to the immediacy or magnitude of that reinforcement. Thus, it appears that signalling whether or not reinforcement will occur at the end of the terminal link has a broad effect: it changes the value of the entire terminal link and reduces sensitivity to all dimensions of reinforcement being manipulated.

In summary, I set out to identify where, and by what behavioural process, signalling has its effect. The first experiment asked about the generality of the signalling effect. It would be informative, for example, if signalling only affected sensitivity to probabilistic reinforcement. An example of the potential implications of this is given in the modified information hypothesis, the 'optimization hypothesis', tentatively developed in Chapter 2. The next two experiments concentrated on procedural factors identified by scrutinising differences between certain and uncertain reinforcement. This scrutiny suggested that there are two differences – greater expected magnitude of reinforcement from the certain alternative and less variability of reinforcement on the certain alternative. The final two experiments investigated where, in models of choice, the signalling effect is best represented. This was driven

primarily by CCM, which describes the relation between preference and the multiple variables of concurrent chains. For the present research, the question becomes how the signalling effect relates to the terminal-link effect and CCM.

7.2: Implications of the present research

Originally it was thought that signalling would only affect sensitivity of preference to reinforcer probability. In CCM, that would be expressed as a change in the exponent of the probability ratio.

$$\frac{B_1}{B_2} = b\left(\frac{R_1}{R_2}\right)^{a_R}\left[\left(\frac{1/D_1}{1/D_2}\right)^{a_D}\left(\frac{M_1}{M_2}\right)^{a_M}\left(\frac{P_1}{P_2}\right)^{a_P}\right]^{Tt/Ti} \tag{7.1}$$

In Equation 7.1, B represents the initial-link responses, R is relative reinforcement rate or terminal-link entry, $1/D$ is immediacy (i.e., the terminal-link delay), M is the magnitude of reinforcement, P is the probability of reinforcement, and the exponent, Tt / Ti, represents the ratio of the average time in the terminal link to time in the initial link, per reinforcer. The subscripts 1 and 2 represent the left and right alternatives, respectively. The remaining exponents (i.e., a_R, a_D, a_M and a_P) represent sensitivity values to each of the dimensions of reinforcement. This model reduces to the concatenated generalised matching law when the initial- and terminal-link durations are equal (i.e., when $Tt = Ti$). CCM deals with the initial- and terminal-link effects by the inclusion of the Tt / Ti exponent. Thus, Equation 7.1 keeps the

integrity of the matching law intact while extending it to account for a wider variety of experimental situations.

Experiments 4 and 5 showed that signalling affects sensitivity of behaviour to *all* dimensions of reinforcement. The evidence for that comes from the generalised-matching analyses that confirmed a reduction in sensitivity of behaviour to reinforcer probability, to reinforcer immediacy and to reinforcer magnitude, in signalled relative to unsignalled conditions. Thus, all exponents within the square, 'terminal-link' bracket of CCM were all affected by signalling whether or not reinforcement was forthcoming.

Furthermore, these parametric experiments showed that signalling affects sensitivity of behaviour to each dimension of reinforcement to approximately the same extent. Further analyses were conducted to quantify the reduction in sensitivity to reinforcer probability and immediacy, and to reinforcer probability and magnitude in signalled relative to unsignalled conditions. The question was whether the reduction in sensitivity was equivalent for reinforcer probability and immediacy (Experiment 4) and for probability and magnitude (Experiment 5). If there were systematic differences in the size of the signalling effect to one variable of reinforcement than the others, it would indicate that signalling has a greater impact on preference for that variable. However, if there were no differences between the sizes of the signalling effect to these reinforcement variables, it would indicate that signalling affects the relative value the terminal links, including all reinforcing variables, as expressed as response allocation.

The size of the signalling effect was calculated separately for reinforcer probability and immediacy, and for reinforcer probability and magnitude. Specifically, the average sensitivity value for the signalled conditions was subtracted from the average value for the unsignalled conditions, and expressed as a proportion of the sensitivity value for the unsignalled conditions: $[(a_{us} - a_s) / a_{us}]$. This analysis revealed that for some subjects, there was greater reduction in sensitivity to reinforcer immediacy (or magnitude), and for other subjects there was greater reduction in sensitivity to reinforcer probability. Across subjects, no consistent patterns were observed. Thus, it appears that signalling affects the relative value of the entire terminal link, by affecting sensitivity to all terminal-link reinforcing variables to a similar degree.

In summary, signalling whether reinforcement will be delivered at the end of the terminal link affects sensitivity to all reinforcing variables (it does not just affect the reinforcer probability exponent), and does so to approximately the same extent. Within the framework offered by CCM, perhaps signalling effects are analogous to effects of temporal context, in that they are global and affect sensitivity to all terminal-link variables to the same degree.

CCM has been used to help explain contextual effects that have often been observed in concurrent-chains procedures (i.e., the initial-link and terminal-link effects) because the *Tt/Ti* exponent captures the effect of variations in initial- and terminal-link durations. Specifically, it enables expression of the fact that the absolute duration of the initial- and terminal-links affects preference. For example, preference for the richer alternative increases as the absolute duration of the terminal

link increases. Conversely, preference for the poorer alternative increases as the absolute terminal-link duration decreases. If signalling shows its effect on sensitivity of choice in the *Tt/Ti* exponent, perhaps the signalling effect and the terminal-link effect are related.

It might be that the terminal-link effect and the signalling effect are analogous. The temporal context of concurrent chains (e.g., the initial- and terminal-link durations) affects preference when the terminal-link outcomes are not signalled. When the terminal links are signalled, these signals affect preference. However, the signalling effect does not seem to be further affected by temporal context. In this way, these two phenomena might have analogous yet opposite effects on preference – the terminal-link effect influences within-alternative preference and the signalling effect influences between-alternative preference. Both effects also appear to have global effects on preference, as they influence sensitivity to all dimensions of reinforcement.

Relatedly, in a comprehensive paper, Dunn and Spetch (1990) systematically varied the duration of the initial and terminal links. Results suggest that the terminal-link effect (increased preference with longer terminal links) may only occur in unsignalled procedures. Their first experiment explored preference in concurrent chains by varying initial- and terminal-link durations and used signalling in the terminal links. Pigeons were required to peck at either an unreliable alternative, where the probability of reinforcement (p(R)) was .67, or a reliable one (p(R) = 1.0). They found that as the terminal-link duration increased, from Fixed Time (FT) 1 s to FT 40 s, preference for the reliable alternative also increased. Furthermore,

preference for the reliable alternative again increased, although only slightly, as the initial-link durations increased from VI 30 s to VI 120 s and terminal links were constant. The results of this experiment suggest that when the outcomes on the unreliable alternative are differentially signalled, the extent of preference for the more reliable alternative is an increasing function of *both* initial- and terminal-link durations.

In a second experiment, Dunn and Spetch sought to compare signalled and unsignalled procedures. They held the duration of the initial link constant and varied the terminal-link duration, thereby varying the degree of exposure to the terminal-link stimuli. The probability of reinforcement on the unreliable alternative was 50%, which was to replicate the percentage used by Kendall (1974, 1985). Reinforcement was certain on the reliable alternative, i.e., P(R) = 1. The stimuli presented during the terminal link were either the same for reinforcement outcomes on both alternatives (signalled-same), differentially correlated with the outcome (S+ and S-; signalled-different), or were uncorrelated with the outcome (unsignalled). They found that preference for the reliable alternative was highest in unsignalled conditions. However, there were no consistent differences in preference between the two signalled conditions. The experiment was also designed to evaluate Kendall's hypothesis that the stimulus paired with reinforcement in the unreliable terminal link has enhanced conditioned-reinforcement value, thereby improving the value of that terminal link, and decreasing preference for the reliable alternative. If this hypothesis is correct, then preference for the reliable alternative should be higher in the signalled-same compared to the signalled-different condition. However, there was no reliable difference between preferences in the two conditions. In summary, the signalling

effect was clearly replicated in their second experiment (which it was not in their first experiment) and Kendall's (1972) additional conditioned reinforcement value hypothesis was not supported.

Dunn and Spetch (1990) conducted a third experiment where the durations of the terminal links were held constant and the initial-link schedules were varied. Again, the experiment provided a direct comparison of signalled and unsignalled procedures. As before, they found that preference for the reliable alternative was strongest in unsignalled conditions and that preference was greater with short initial links. In fact, preference for the reliable alternative was below 50% for three of the five birds. In summary, preference for the reliable alternative was less in signalled conditions than in unsignalled conditions. The results of these experiments show that preference is determined by initial-link schedules, terminal-link durations, and stimulus conditions in the terminal link. However, the role of the terminal-link stimuli has not yet been made clear because Experiment 2 failed to support Kendall's hypothesis concerning conditioned-reinforcement value.

In summary, Dunn and Spetch conducted experiments where the terminal-link duration was varied in either signalled or unsignalled conditions, the terminal-link effect only occurred in unsignalled conditions. In other conditions, where the duration of the terminal link was constant, the signalling effect was obtained. Thus, this also suggests that the magnitude of the signalling effect may be affected by the duration of the terminal links, i.e., a stronger signalling effect may be observed with longer terminal links. If signalling and short terminal links affect preference through the same process, then these results should have been equivalent. With longer

terminal links, the signalling effect should be larger than with shorter terminal links, because of the strong terminal-link effect in unsignalled terminal links combined with the weaker terminal-link effect in signalled terminal links. Since the signalling effect is the difference between preference in unsignalled and signalled conditions, the signalling effect should be larger with longer terminal links. Thus, signalling leaves no room for the terminal-link effect. The critical question therefore, is whether the effects of signalling and the terminal-link duration are independent.

Dunn and Spetch also suggested that the function of terminal-link stimuli was to bring forward (in time) reinforcement because the stimuli are presented at the beginning of the terminal link. Preference may be swayed toward the alternative with the more immediate reinforcement, conditioned or otherwise. Perhaps this is why a reduction in preference for the reliable alternative is seen in signalled conditions relative to unsignalled conditions. We know that reduced preference is often found with shorter terminal links (i.e., the terminal-link effect; MacEwen, 1972); thus, if the function of the terminal-link stimuli is to bring forward reinforcement in time, it is not surprising that a reduced preference for the more reliable alternative is obtained in signalled conditions. Furthermore, it suggests that these two effects may be related, if not analogous.

If the terminal-link effect and the signalling effect are related, then as the absolute terminal-link duration increases the magnitude of the signalling effect should also increase. The present Experiment 2 made an attempt to investigate this by increasing the absolute duration of the terminal links. Analyses revealed that there was very little change in preference and the magnitude of the signalling effect as the

duration of the terminal link increased. However, it was only a modest attempt with two birds and only a small range of terminal-link durations. Over a wider range of terminal-link values, it may be that the magnitude of the signalling effect increases with increases in absolute duration of terminal links. If the magnitude of the signalling effect does not change as absolute terminal-link durations increase, then it would indicate that the same behavioural process (bringing forward reinforcement in time) does not underlie both the terminal-link effect and the signalling effect.

Over variations in absolute terminal-link duration, would the preference for fixed over variable magnitudes of reinforcement remain? If the magnitude of the signalling effect is determined in part by the absolute duration of the terminal links, then it seems likely that in signalled conditions the preference for fixed over variable magnitudes would reduce as terminal-link duration decreased – if signalling does reduce the preference for fixed over variable magnitudes of reinforcement as hypothesised. If the absolute duration of the terminal link affects the magnitude of the preference for fixed over variable magnitudes of reinforcement, then it would further indicate a relationship between the terminal-link effect and the signalling effect.

In summary, the evidence suggests that the terminal-link effect and the signalling effect are related. Dunn and Spetch found that the terminal-link effect only occurred in unsignalled conditions, and the present Experiment 2 found that the absolute duration of the terminal link did not affect the magnitude of the signalling effect. It appears that these two effects are underpinned by the same behavioural mechanism – the function of correlated terminal-link stimuli is to bring forward

reinforcement in time, shortening the terminal links thus resulting in the signalling effect.

A hypothesis proposed earlier was that probabilistic reinforcement is inherently variable, and signalling in the unreliable alternative acts to increase the predictability of that reinforcement; resulting in a reduced preference for the certain alternative. Experiment 2 specifically manipulated the relative variability of reinforcement across conditions; however, all the other experiments also involved variability of reinforcement – either variable reinforcer immediacy or magnitude, and of course reinforcer probability. The signalling effect observed in these experiments may be a result of the correlated stimuli increasing the predictability of the forthcoming reinforcers.

From here, we shall turn to discussion of a model of conditioned reinforcement that has been popular in describing results in concurrent chains and in signalling procedures – the Delay Reduction Hypothesis (DRH; Fantino, 1969; Squires & Fantino, 1971).

7.3: Conditioned Reinforcement

The major contemporary theory of conditioned reinforcement is the Delay Reduction Hypothesis (DRH; Fantino, 1969; Squires & Fantino, 1971). It states that a terminal-link stimulus acquires conditioned reinforcement strength when it is correlated with a reduction in time to primary reinforcement. Furthermore, preference will become stronger in an alternative with additional conditioned reinforcement

value (from the stimulus), when the stimulus signals a reduction in time, relative to the average time, to primary reinforcement.

$$\frac{P_1}{P_1 + P_2} = \frac{T - t_1}{(T - t_1) + (T - t_2)} \tag{7.2}$$

Equation 7.2 is a simplified version of the DRH. P is the number of initial-link pecks, T is the average time to primary reinforcement since the onset of the initial links (average initial-link and terminal-link duration), t is the terminal-link duration, and the subscripts 1 and 2 represent the left and right alternatives, respectively. Preference is determined by a relative reduction in T. This model has received much support over the years and has remained a prominent model in the field of choice and conditioned reinforcement.

Other researchers have attempted to apply DRH to experimental situations involving dimensions of reinforcement other than delay. Spetch and Dunn (1987) investigated probabilistic reinforcement while varying the initial- and terminal-link schedules, and then extended the DRH to account for choice for probabilistic reinforcement. I will briefly describe their research and then examine how they applied DRH to it.

In their experiments, the eventual outcome of each trial was never differentially signalled by terminal-link stimuli. The percentage of reinforced trials on the *more reliable* alternative was either 100 or 50%. On the *less reliable* alternative, the percentage of reinforced trials was either 50 or 25%. Thus, the relative percentage was held constant while the overall absolute percentage of

reinforcement was varied across conditions. They found a strong, consistent preference for the more reliable alternative, which did not vary with absolute percentage of reinforcement. In a second experiment, they tested this preference by varying absolute initial- and terminal-link durations across conditions. They found that preference for the more reliable alternative was more extreme with shorter initial links and longer terminal links. This replicates the initial-link and terminal-link effects described earlier. In a third experiment, Spetch and Dunn used equal probabilities with unequal delays to reinforcement and varied the absolute percentage of reinforcement. They found the expected preference for the shorter terminal link, and this was not systematically affected by changes in absolute percentage of reinforced trials. Overall, they found that subjects preferred the more reliable alternative and that the level of preference was not affected by changes in absolute percentage of reinforcement. Thus, these experiments support application of the generalised matching law to choice between alternatives differing in reinforcer probability.

Spetch and Dunn suggest that reinforcement probabilities can be 'transformed' into delay values, and the model applied. Thus, DRH could account for choice with probabilistic reinforcement as well as delayed reinforcement, given that percentage reinforcement affects the duration of access to reinforcement, per unit of time in the terminal links (Spetch & Dunn, 1987). In this way, the parameters t_1 and t_2, become the product of the probability and duration of each terminal link, rather than simply the terminal-link duration as in the original DRH. They give an example, with equal initial-link durations (VI 90 s) and equal terminal-link durations (FI 15 s), but unequal probabilities, 100% reinforcement on the left and 50% reinforcement on the right, the

values for the equation become: $t_1 = 15/1$ (15 s), $t_2 = 15/0.5$ (30 s) and T would therefore be calculated as $0.5(90) + 0.5(15) + 0.5(30) = 67.5$. When these values are used in Equation 7.2, the predicted choice proportion is 0.58 (i.e., preference for the certain alternative).

Spetch and Dunn further explained that when terminal-link delays (t) are transformed by multiplying with probability of reinforcement (p), T no longer represents mean time to reinforcement from onset of the initial links because the different probabilities of the outcomes were not taken into account. In this example, the mean interoutcome interval is $0.5(90) + 0.5(15) + 0.5(15) = 60$ s. Therefore they suggested that the following calculation, taking into account probabilities of the outcome, should be used: $60/ ((0.5 + 1.0)\ 0.5) = 80$ s. Thus, the outcome on the left should actually be the product of the probability of reinforcement and duration of terminal link ($p_1(t_1)$), with time to reinforcement on the left determined as $p_1(t_1) + ((1 - p_1)\ (t_1 + T))$. Furthermore, the mean reduction in time to reinforcement following the onset of the left terminal link would then be $T - \{p_1(t_1) + ((1 - p_1)\ (t_1 + T))\}$; which simplifies to $Tp_1 - t_1$. The extension to DRH will then be Equation 7.3,

$$\frac{P_1}{P_1 + P_2} = \frac{Tp_1 - t_1}{(Tp_1 - t_1) + (Tp_2 - t_2)} \tag{7.3}$$

Using this equation and the values from the above example, $(80(1.0) - 15) / \{(80(1.0) - 15) + (80(0.5) - 15)\}$, the predicted choice proportion is 0.72. This is a much higher predicted preference than the one made by Equation 7.2. Spetch and Dunn went on to show that Equation 7.3 provided a more accurate prediction of response allocation than did Equation 7.2. This suggests that their extension with the

transformation of probabilities into delay values was accurate. Furthermore, DRH can be applied to percentage-reinforcement procedures as probabilistic reinforcers can be considered analogous to delayed reinforcers (Spetch & Dunn, 1987).

Others have attempted to apply DRH to procedures where different magnitudes of reinforcement are delivered. Navarick and Fantino (1972) suggested this application was simply a matter of transforming magnitude values into delay values. Basically, the parameter for reinforcer magnitudes used was the product of rate and magnitude of reinforcement (i.e., the number of seconds of reinforcement per unit of terminal-link time). They assumed that a FI 5 s schedule with a 4.5 s reinforcer was equivalent to a FI 1.7 s schedule with a 1.5 s reinforcer. Given this transformation, the DRH provides an adequate prediction of response allocation between two alternatives with different magnitudes of reinforcement. However, this account does not really deal with magnitude because it is not always simply a case of converting one to the other, what about variable magnitudes of reinforcement being delivered from the same alternative? This account implies that how magnitudes of reinforcement are constituted should not matter; they work on an averaging system, where it is the average magnitude of reinforcement on each alternative that determines preference. This would not account for the preference for fixed over variable magnitudes of reinforcement. Furthermore, can reinforcer delay and magnitude really be placed on the same scale? Is preference affected in the same way by reinforcer delay and magnitude of reinforcement?

Fantino (1977) suggests that reinforcer delay and magnitude are comparable in the ways mentioned above. He simply assumes that temporal context affects choice

between two magnitudes in the same way as it does between two rates or delays of reinforcement, thus magnitudes can easily be transformed into delay values and the model applied. This rests on the assumption that delay and magnitude have the same effects on preference. However, it has been reported numerous times that sensitivity to delay is usually higher than sensitivity to reinforcer magnitude. Thus, it may not be appropriate to transform magnitude values into delay values in the manner proposed by Fantino (1977) and Navarick and Fantino (1972) – their treatment of reinforcer magnitude seems to be a purely quantitative account. How does a model of conditioned reinforcement do when applied to data from a procedure in which reinforcer magnitude is varied, or when relative variability of reinforcement is manipulated?

I will apply a conditioned-reinforcement perspective (DRH) to each of the present experiments. Remember that according to this perspective, a stimulus that signals a reduction in the average time to reinforcement acquires additional conditioned reinforcing strength, and thus adds conditioned reinforcing value to that alternative. Beginning with Experiment 1, reinforcement on the right alternative was certain and always the same, therefore the stimuli would not acquire any additional conditioned reinforcing value. However, on the uncertain alternative, either the probability or the magnitude of reinforcement varied; therefore, stimuli associated with reinforcement in the probabilistic conditions, and stimuli associated with the larger magnitude of reinforcement in the magnitude-based conditions, would acquire additional conditioned reinforcing strength. In the second condition of Experiment 1, the green stimulus on the left alternative was associated with reinforcement, whereas the blue stimulus was associated with extinction. Therefore, the green stimulus would

add value to left alternative in signalled conditions. In the third condition, terminal links were unsignalled thus there was no additional conditioned reinforcing value from either stimulus. On this basis, we would expect stronger preference for the right (certain) alternative in Condition 3 than in Condition 2. This was indeed what was obtained: stronger preference for the certain alternative in the unsignalled relative to the signalled condition. In the fourth condition, the probabilities of reinforcement on the left (uncertain) alternative were .33 and .67, obviously more similar than probabilities of 0 and 1, in Condition 2. From a conditioned-reinforcement perspective, it would be expected that the stimulus associated with .67 probability of reinforcement would still have conditioned reinforcing value, but it would be less than the stimulus associated with 100% reinforcement (i.e., green in Condition 2). Therefore, one would expect stronger preference for the right alternative in Condition 4 than in Condition 2, because there would be less conditioned reinforcing value on the uncertain alternative in Condition 4. However, analyses revealed that preference for the certain alternative was similar in both Conditions 2 and 4. Further, this approach predicts that preference would be similar in Conditions 4 and 5. In Condition 4, the probabilities of reinforcement associated with each stimulus on the unreliable alternative were .33 and .67. In Condition 5, reinforcement on the unreliable side was certain but the magnitudes of reinforcement varied; they were either 1.2 s or 2.3 s duration. If, when magnitude of reinforcement is signalled, the conditioned reinforcing strength is allocated according to the reduction in delay to the larger reinforcer (2.3 s), then the stimulus associated with that reinforcer would acquire additional value (to the same degree as the stimulus associated with the .67 probability of reinforcement in Condition 4). Therefore, preference for the reliable alternative should be the same in these two conditions. However, analysis showed

that preference for the certain alternative was considerably stronger in Condition 5 (magnitude-based condition) than in Condition 4 (probability-based condition). This suggests that the stimuli signalling whether or not reinforcement is forthcoming have a greater effect on preference than stimuli that signal which of two magnitudes of reinforcement are due. Overall, it seems as though a conditioned-reinforcement perspective has difficulty dealing with conditions in which the magnitude of reinforcement is signalled.

Experiment 2 also signalled mixed magnitudes of reinforcement – does a conditioned reinforcement approach predict the results from this experiment? Reinforcement was certain on both alternatives and the expected magnitudes of reinforcement were equal. The first condition was a baseline condition, where both alternatives offered signalled terminal links ending with either a large or a small reinforcer. Each alternative had equal expected magnitude of reinforcement and equal conditioned reinforcing value; thus indifference was predicted and it was obtained. In Condition 2, reinforcement on the right was always the same, thus there was no additional conditioned reinforcing value on that alternative. On the left however, the green stimulus was correlated with the larger reinforcer, thus it added conditioned-reinforcing value to that alternative. A conditioned-reinforcement perspective would therefore predict a shift in preference towards the left alternative in this condition. However, subjects remained indifferent between the alternatives. Furthermore, post-reversal there was no consistent shift in preference towards the right alternative (which then had the stimulus associated with the larger reinforcer). In Condition 3, reinforcers on the left alternative remained the same as in Condition 2 (signalled variable), and reinforcement outcomes on the right alternative were unsignalled

variable magnitudes, therefore a similar level of preference in these two conditions was expected. Initially, subjects remained indifferent between the two (they still did not prefer the left alternative as predicted from a conditioned-reinforcement perspective); however, all subjects shifted towards the right alternative when contingencies were reversed across alternatives. The shift in preference was consistent with predictions from this perspective. In Condition 4, reinforcement on the right alternative was fixed (always 4.5 s reinforcer) and reinforcement on the left was unsignalled variable magnitudes. Neither alternative had additional conditioned reinforcement value, therefore indifference is predicted. However, a moderate preference for the right alternative was found pre-reversal, and all birds shifted towards the left alternative post reversal – neither of which was predicted from a conditioned-reinforcement perspective. However, this preference was predicted from a fixed-over-variable perspective – subjects initially preferred the right alternative (fixed) and shifted towards the left when the contingencies were reversed – this supports the notion that subjects prefer fixed over variable magnitudes of reinforcement. Overall, these results are only partly consistent with predictions from a conditioned-reinforcement perspective.

In Experiment 3, the relative expected magnitude of reinforcement was varied across alternatives. Each alternative delivered either a small or a large reinforcer. The ratio of expected magnitude of reinforcement across alternatives was 3:1, and it is expected in unsignalled conditions that preference reflect the ratio of reinforcement. In signalled conditions, because both alternatives offered a small and a large reinforcer magnitude, they would have the same conditioned-reinforcing value associated with the larger reinforcer. Therefore, the same level of preference for the

alternative with the greater expected magnitude of reinforcement is predicted in both signalled and unsignalled conditions. Indeed, similar levels of preference were obtained across conditions.

Finally, in Experiments 4 and 5, relative probability of reinforcement was varied across conditions, while the relative reinforcer delay or magnitude was varied across components. The probability of reinforcement was either 33 and 67% or 17 and 83%. In signalled conditions, the stimulus associated with reinforcement on the 17% alternative should acquire the most conditioned reinforcement value, because when it occurs it signals the greatest reduction in the average time to reinforcement. Therefore, it seems likely that the magnitude of the signalling effect would be greater in conditions with a more extreme reinforcer probability ratio. Analysis revealed that the reduction in preference for the more reliable alternative in signalled relative to unsignalled conditions was greater in the 17 to 83% conditions relative to the 33 to 67% conditions. A conditioned-reinforcement perspective appears to predict the results from these two experiments; however, because the stimuli were informative as to the availability of reinforcement not the immediacy or magnitude of that reinforcement, it cannot account for the secondary effect obtained – the reduced sensitivity of behaviour to the other independent variable.

Overall, a conditioned-reinforcement perspective can predict preference in conditions where only the relative expected magnitude of reinforcement varies (as in Experiment 3) but cannot predict preference in conditions where the relative variability of reinforcement varies (as in Experiment 2). Because some of the results from both Experiments 1 and 2 were not predicted by a conditioned-reinforcement

perspective – particularly when relative variability of reinforcement was varied. Furthermore, it is unable to predict the reduced sensitivity to the non-signalled independent variable in Experiments 4 and 5.

7.4: Conclusions

Results from Experiment 1 indicated that the signalling effect was stronger when the terminal link signals indicated whether or not reinforcement was due, rather than which of two reinforcer magnitudes were forthcoming. One possible reason that signalling has such an effect on preference for probabilistic reinforcement is because it is inherently variable, and signalling acts to reduce the preference for fixed magnitudes. Thus, sensitivity to relative reinforcement is reduced in signalled compared to unsignalled conditions, when that reinforcement is variable. Results from Experiment 2 supported this hypothesis, overall subjects preferred fixed over variable magnitudes of reinforcement, and this preference was reduced when variable magnitudes were signalled. Signalling might also act on preference for expected magnitude, reducing preference for the larger of two expected magnitudes thus resulting in more equal response allocation between two alternatives. Experiment 3 investigated this possibility and found no evidence of a signalling effect when relative expected magnitude changed but relative variability of reinforcement remained constant.

How would signalling the availability of reinforcement affect sensitivity to other variables of reinforcement? Experiments 4 and 5 investigated this question. In Experiment 4, relative probability and relative immediacy of reinforcement were

varied parametrically; and in Experiment 5 relative probability and relative magnitude of reinforcement were varied parametrically. In both experiments, sensitivity to reinforcer probability was reduced in signalled relative to unsignalled conditions. Moreover, sensitivity of behaviour to the other independent variable, i.e., reinforcer immediacy or magnitude, was also reduced. This suggests that signalling reinforcement outcomes has a global effect on sensitivity to all variables of reinforcement.

Together these results support the signalling effect. Importantly, the fact that signalling whether or not reinforcement will occur at the end of the terminal link reduces sensitivity to relative probability of reinforcement, and also reduces sensitivity to the other independent variable was not known before these experiments were conducted. Neither had parametric investigations of reinforcer probability and immediacy/magnitude been conducted. These experiments challenge current models of choice to adequately describe and predict behaviour in signalled procedures.

Models of conditioned reinforcement have been applied to data from signalling procedures, with variable success. Fantino's Delay Reduction Hypothesis (DRH) and subsequent extensions of it (i.e., Spetch & Dunn, 1987, percentage-reinforcement procedures) have been applied to signalling procedures; however, because DRH is a model based on reinforcer delay, there are difficulties in applying it to conditions where the magnitude of reinforcement is manipulated, rather than the immediacy of reinforcement.

The results of these experiments also indicate that the terminal-link effect and the signalling effect might be related, because the terminal-link effect only seems to occur in unsignalled terminal links, and the magnitude of the signalling effect does not seem to be affected by terminal-link duration.

7.5: Future directions

It would be fruitful to re-run Experiment 1 using a similar procedure as Experiment 3: a two-component concurrent-chains procedure with number of hopper presentations as reinforcement. Further, the most accurate measure of change in preference seemed to be obtained when comparing conditions that were run successively. In this way, the position and schedule reversals would be conducted successively within a session, thus reducing the possibility of non-reversal as observed in Experiment 1 and any between-session bias. If similar results were obtained – specifically, that the magnitude of the signalling effect is greater when the signals indicate if reinforcement is forthcoming (probabilistic conditions), rather than what size that reinforcement is (magnitude-based conditions) – we could conclude that the original findings were robust. At this stage, the results of the reversal conditions cast doubt on the solidity of the results.

It may also be informative to conduct Experiment 2 again, in a two-component procedure in order to eliminate any difficulties with reversals. Moreover, it would permit direct comparison of the influence of signalling on preference between alternatives with variable reinforcement but equal expected magnitudes (Experiment 2) and alternatives with fixed reinforcement but unequal expected

magnitudes (Experiment 3). At this stage, we are able to compare the results of these two experiments; however, we are unsure as to the effect of procedural differences. Thus, conducting Experiment 2 using the same procedure as Experiment 3 should resolve that issue.

A more extensive investigation of the magnitude of the signalling effect over a wide range of absolute terminal-link durations is essential to pinpoint the relation between the terminal-link effect and the signalling effect. Whether terminal-link schedule durations have an impact on the magnitude of the signalling effect has yet to be adequately addressed, and is therefore an issue for future research.

Returning to CCM, the results of Experiments 4 and 5 have demonstrated that signalling affects each of the exponents in the square 'terminal-link' bracket. Because these experiments did not explicitly address the 'initial-link section' of Equation 7.1 (R_1/R_2), it is unclear exactly how signalling may affect sensitivity to terminal-link entry. As far as we know this has not yet been investigated and is therefore an issue to address in future research. Moreover, without knowledge of how unequal terminal-link entry affects preference for signalled or unsignalled terminal links of various durations, we can not be confident in the conclusion that the signalling effect has its effect in the terminal link.

One of the overall goals of the present research was to pinpoint where and by what behavioural mechanisms signalling had its effect. These experiments have indicated that signalling influences the relative value of the terminal links, not just sensitivity to reinforcer probability, and that temporal context may play an important

role in determining the magnitude of the signalling effect. Furthermore this research has indicated that the terminal-link effect and the signalling effect are both global influences on sensitivity of choice and therefore may be related. Completion of additional aforementioned experimental programmes may help fill in any missing pieces.

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APPENDICES

Appendix 1: Individual data from Experiment 1, responses on the left and right alternatives, from the last five sessions and the choice proportion

Cond	E5			E6			E7			E8		
	BL	BR	CP(L)	BL	BR	CP(L)	BL	BR	CP(L)	BL	BR	CP(L)
1	803	703	0.53	680	690	0.5	309	427	0.42	624	612	0.5
	1013	684	0.6	379	496	0.43	337	415	0.45	633	739	0.46
	775	614	0.56	760	566	0.57	262	381	0.41	619	636	0.49
	819	739	0.53	781	547	0.59	343	478	0.42	629	657	0.49
	862	757	0.53	718	575	0.56	280	475	0.37	579	578	0.5
Av	854	699	0.55	664	575	0.53	306	435	0.41	617	644	0.49
2	623	775	0.45	369	909	0.29	177	623	0.22	406	1116	0.27
	587	869	0.4	436	911	0.32	150	489	0.23	260	949	0.22
	722	902	0.44	482	872	0.36	141	544	0.21	315	1044	0.23
	581	891	0.39	463	845	0.35	145	760	0.16	364	985	0.27
	672	874	0.43	371	976	0.28	132	496	0.21	362	987	0.27
Av	637	862	0.42	424	903	0.32	149	582	0.21	341	1016	0.25
3	213	1573	0.12	169	798	0.17	118	727	0.14	230	1023	0.18
	196	1698	0.1	177	766	0.19	117	744	0.14	253	850	0.23
	183	1323	0.12	197	942	0.17	105	725	0.13	269	1241	0.18
	210	1347	0.13	168	927	0.15	108	791	0.12	277	1252	0.18
	183	1340	0.12	186	855	0.18	121	657	0.16	293	1196	0.2
Av	197	1456	0.12	179	858	0.17	114	729	0.14	264	1112	0.19
4	676	1086	0.38	496	933	0.35	122	809	0.13	388	461	0.46
	647	1087	0.37	432	822	0.34	230	1057	0.18	521	513	0.5
	468	793	0.37	420	910	0.32	112	715	0.14	561	562	0.5
	605	993	0.38	270	643	0.3	140	962	0.13	425	452	0.48
	485	863	0.36	498	935	0.35	181	1100	0.14	694	660	0.51
Av	576	964	0.37	423	849	0.33	157	929	0.14	518	530	0.49
5	290	1482	0.16	220	1140	0.16	75	1401	0.05	476	1149	0.29
	319	1475	0.18	245	1135	0.18	128	1614	0.07	385	1384	0.22
	307	1464	0.17	255	969	0.21	71	848	0.08	235	923	0.2
	279	1375	0.17	276	1027	0.21	70	1130	0.06	362	1211	0.23
	212	1036	0.17	159	651	0.2	62	1057	0.06	323	979	0.25
Av	281	1366	0.17	231	984	0.19	81.2	1210	0.06	356	1129	0.24
6	195	1944	0.09	131	737	0.15	91	1265	0.07	320	1172	0.21
	148	1294	0.1	231	1091	0.17	156	1656	0.09	316	960	0.25
	228	1691	0.12	200	737	0.21	73	1500	0.05	253	968	0.21
	261	1539	0.15	171	730	0.19	94	1881	0.05	233	1141	0.17
	158	1090	0.13	164	788	0.17	91	1520	0.06	217	833	0.21
Av	198	1512	0.12	179	817	0.18	101	1564	0.06	268	1015	0.21

4A	464	1051	0.31	350	767	0.31	186	1113	0.14	576	495	0.54
	440	1035	0.3	199	415	0.32	261	1289	0.17	598	409	0.59
	397	786	0.34	207	561	0.27	206	1406	0.13	812	553	0.59
	533	1037	0.34	327	744	0.31	145	1140	0.11	566	482	0.54
	462	1007	0.31	300	645	0.32	179	1405	0.11	630	452	0.58
Av	459	983	0.32	277	626	0.31	195	1271	0.13	636	478	0.57
2R	1157	234	0.83	582	174	0.77	236	932	0.2	1285	172	0.88
	1280	209	0.86	1104	284	0.8	121	712	0.15	1420	233	0.86
	1277	198	0.87	1204	232	0.84	163	939	0.15	1439	169	0.89
	1319	183	0.88	1028	260	0.8	182	1092	0.14	1103	134	0.89
	1369	222	0.86	1125	236	0.83	178	1300	0.12	1025	119	0.9
Av	1280	209	0.86	1009	237	0.81	176	995	0.15	1254	165	0.88
3R	1418	242	0.85	635	195	0.77	185	670	0.22	1,366	127	0.91
	1101	219	0.83	764	177	0.81	285	782	0.27	1407	129	0.92
	1242	337	0.79	726	231	0.76	177	646	0.22	1180	113	0.91
	1030	219	0.82	838	309	0.73	235	722	0.25	1279	167	0.88
	1388	297	0.82	1026	259	0.8	156	726	0.18	1363	164	0.89
Av	1236	263	0.82	798	234	0.77	208	709	0.22	1319	140	0.9
4R	1630	400	0.8	704	195	0.78	317	606	0.34	1018	306	0.77
	1192	609	0.66	979	262	0.79	261	666	0.28	839	165	0.84
	1030	324	0.76	793	176	0.82	308	676	0.31	839	156	0.84
	1272	406	0.76	797	143	0.85	198	542	0.27	840	201	0.81
	888	282	0.76	1056	305	0.78	194	448	0.3	863	222	0.8
Av	1202	404	0.75	866	216	0.8	256	588	0.3	880	210	0.81
5R	1434	157	0.9	928	204	0.82	275	869	0.24	1236	167	0.88
	1410	251	0.85	874	207	0.81	265	784	0.25	1134	144	0.89
	1191	254	0.82	877	121	0.88	156	603	0.21	1283	207	0.86
	1153	284	0.8	741	125	0.86	163	463	0.26	1295	170	0.88
	1254	155	0.89	1130	199	0.85	247	787	0.24	1163	193	0.86
Av	1288	220	0.85	910	171	0.84	221	701	0.24	1222	176	0.87
6R	1450	173	0.89	1065	212	0.83	327	712	0.31	834	143	0.85
	2,015	149	0.93	1,029	210	0.83	343	737	0.32	1,063	282	0.79
	1902	114	0.94	1072	198	0.84	291	671	0.3	1045	282	0.79
	1923	160	0.92	950	193	0.83	284	689	0.29	885	180	0.83
	1314	130	0.91	1116	176	0.86	254	810	0.24	1070	285	0.79
Av	1721	145	0.92	1046	198	0.84	300	724	0.29	979	234	0.81

Appendix 2: Individual data from Experiment 2, responses on the left and right alternatives, from the last five sessions and the choice proportion

Cond	Q5			Q6			Q7			Q8		
	BL	BR	CP(L)	BL	BR	CP(L)	BL	BR	CP(L)	BL	BR	CP(L)
T1	538	225	0.705				425	104	0.803	1292	128	0.91
	578	189	0.754				713	88	0.89	1345	163	0.892
	694	207	0.77				759	131	0.853	1411	149	0.904
	473	155	0.753				1028	153	0.87	1339	166	0.89
	585	212	0.734				742	155	0.827	1470	181	0.89
Av	573.6	197.6	0.743				733.4	126.2	0.849	1371	157.4	0.897
T2	297	1016	0.226				174	929	0.158	238	1611	0.129
	239	983	0.196				209	1141	0.155	230	1670	0.121
	277	1037	0.211				120	1080	0.1	258	1741	0.129
	293	1071	0.215				163	1092	0.13	227	1749	0.115
	301	1022	0.228				181	1014	0.151	266	1657	0.138
Av	281.4	1026	0.215				169.4	1051	0.139	243.8	1686	0.126
					new bird							
1	497	573	0.464	407	338	0.546	411	463	0.47	633	732	0.464
	532	480	0.526	535	405	0.569	333	435	0.434	578	718	0.446
	574	560	0.506	511	437	0.539	380	508	0.428	682	803	0.459
	485	580	0.455	501	407	0.552	494	565	0.466	519	676	0.434
	432	655	0.397	387	347	0.527	405	459	0.469	528	692	0.433
Av	504	569.6	0.47	468.2	386.8	0.547	404.6	486	0.453	588	724.2	0.447
2	534	472	0.531	420	270	0.609	523	532	0.496	382	897	0.299
	567	663	0.461	814	472	0.633	661	415	0.614	437	1058	0.292
	565	558	0.503	507	485	0.511	649	513	0.559	511	860	0.373
	544	653	0.454	655	444	0.596	661	555	0.544	496	891	0.358
	553	556	0.499	451	343	0.568	630	553	0.533	455	1062	0.3
Av	552.6	580.4	0.49	569.4	402.8	0.583	624.8	513.6	0.549	456.2	953.6	0.324
2R	645	566	0.533	385	459	0.456	470	435	0.519	590	916	0.392
	671	640	0.512	380	425	0.472	488	436	0.528	411	803	0.339
	629	653	0.491	400	473	0.458	468	409	0.534	401	874	0.315
	600	576	0.51	414	505	0.45	396	494	0.445	548	788	0.41
	593	609	0.493	406	555	0.422	438	431	0.504	566	807	0.412
Av	627.6	608.8	0.508	397	483.4	0.452	452	441	0.506	503.2	837.6	0.373
3	664	806	0.452	356	689	0.341	369	322	0.534	646	618	0.511
	763	582	0.567	341	655	0.342	462	337	0.578	644	772	0.455
	577	661	0.466	398	673	0.372	432	288	0.6	594	710	0.456
	650	571	0.532	495	502	0.496	466	394	0.542	566	835	0.404
	724	600	0.547	449	656	0.406	430	347	0.553	684	668	0.506
Av	675.6	644	0.513	407.8	635	0.391	431.8	337.6	0.562	626.8	720.6	0.466

3R	458	587	0.438	333	623	0.348	277	398	0.41	582	904	0.392
	509	711	0.417	379	686	0.356	336	506	0.399	596	835	0.416
	578	722	0.445	286	633	0.311	303	417	0.421	536	1006	0.348
	576	828	0.41	356	622	0.364	330	413	0.444	566	1057	0.349
	529	832	0.389	302	584	0.341	347	485	0.417	616	860	0.417
Av	530	736	0.42	331.2	629.6	0.344	318.6	443.8	0.418	579.2	932.4	0.384
4	602	572	0.513	268	556	0.325	452	523	0.464	433	1170	0.27
	552	599	0.48	321	624	0.34	453	401	0.53	408	1156	0.261
	620	545	0.532	266	777	0.255	526	475	0.525	463	806	0.365
	654	593	0.524	287	684	0.296	460	482	0.488	397	1177	0.252
	692	594	0.538	355	736	0.325	456	468	0.494	432	1140	0.275
Av	624	580.6	0.517	299.4	675.4	0.308	469.4	469.8	0.5	426.6	1090	0.285
4R	647	441	0.595	388	567	0.406	906	344	0.725	512	909	0.36
	808	427	0.654	466	555	0.456	875	379	0.698	504	935	0.35
	825	383	0.683	434	526	0.452	885	343	0.721	491	739	0.399
	921	502	0.647	338	457	0.425	783	400	0.662	554	806	0.407
	788	532	0.597	427	529	0.447	782	370	0.679	526	746	0.414
Av	797.8	457	0.635	410.6	526.8	0.437	846.2	367.2	0.697	517.4	827	0.386
5				327	722	0.312	277	398	0.41	532	800	0.399
				300	681	0.306	336	506	0.399	585	645	0.476
				330	810	0.289	303	417	0.421	493	821	0.375
				315	625	0.335	330	413	0.444	454	771	0.371
				274	624	0.305	347	485	0.417	497	674	0.424
Av				309.2	692.4	0.309	318.6	443.8	0.418	512.2	742.2	0.409
5R				427	520	0.451	369	322	0.534	559	667	0.456
				467	534	0.467	462	337	0.578	427	676	0.387
				435	509	0.461	432	288	0.6	519	743	0.411
				388	364	0.516	466	394	0.542	484	849	0.363
				393	393	0.5	430	347	0.553	570	765	0.427
Av				422	464	0.479	431.8	337.6	0.562	511.8	740	0.409
4 TL	599	648	0.48				384	215	0.641			
	472	499	0.486				538	452	0.543			
	101	112	0.474				539	284	0.655			
	595	554	0.518				509	298	0.631			
	551	628	0.467				511	361	0.586			
Av	463.6	488.2	0.485				496.2	322	0.611			
4R TL	615	383	0.616				584	407	0.589			
	673	407	0.623				443	287	0.607			
	600	398	0.601				231	118	0.662			
	582	372	0.61				212	144	0.596			
	553	533	0.509				363	273	0.571			
Av	604.6	418.6	0.592				366.6	245.8	0.605			

Appendix 3: Individual data from Experiment 3, responses on the left and right alternatives, from the last ten sessions of Components 1 and 2, and the choice proportion

	Q5			Q6			Q7			Q8		
Sig	BL C1	BR C1	CP(L)	BL C1	BR C1	CP(L)	BL C1	BR C1	CP(L)	BL C1	BR C1	CP(L)
	419	138	0.752	97	512	0.159	359	125	0.742	0	0	
	345	96	0.782	94	456	0.171	577	127	0.82	213	571	0.272
	349	103	0.772	138	421	0.247	429	116	0.787	158	566	0.218
	392	114	0.775	101	588	0.147	377	135	0.736	183	482	0.275
	347	99	0.778	85	563	0.131	498	133	0.789	224	687	0.246
	355	130	0.732	96	480	0.167	428	173	0.712	177	716	0.198
	382	197	0.66	84	559	0.131	417	160	0.723	200	688	0.225
	292	115	0.717	121	581	0.172	446	106	0.808	203	690	0.227
	350	117	0.749	83	515	0.139	337	131	0.72	345	540	0.39
	344	124	0.735	124	396	0.238	374	131	0.741	137	612	0.183
Av	357.5	123.3	0.745	102.3	507.1	0.17	424.2	133.7	0.758	184	555.2	0.248
						0.83						0.752
Sig	BL C2	BR C2	CP(L)	BL C2	BR C2	CP(L)	BL C2	BR C2	CP(L)	BL C2	BR C2	CP(L)
	93	505	0.156	583	72	0.89	224	207	0.52	0	0	
	122	549	0.182	487	67	0.879	238	216	0.524	358	320	0.528
	95	688	0.121	497	96	0.838	225	242	0.482	0	0	
	92	469	0.164	437	95	0.821	155	188	0.452	563	178	0.76
	86	523	0.141	497	80	0.861	177	290	0.379	0	0	
	105	737	0.125	498	54	0.902	173	330	0.344	351	186	0.654
	93	588	0.137	498	73	0.872	164	438	0.272	672	193	0.777
	86	543	0.137	470	70	0.87	143	512	0.218	433	151	0.741
	111	621	0.152	352	62	0.85	123	348	0.261	530	194	0.732
	98	563	0.148	337	55	0.86	107	429	0.2	316	40	0.888
Av	98.1	578.6	0.146	465.6	72.4	0.864	172.9	320	0.365	322.3	126.2	0.726
						0.136						0.274
Unsig	BL C1	BR C1	CP(L)	BL C1	BR C1	CP(L)	BL C1	BR C1	CP(L)	BL C1	BR C1	CP(L)
	300	71	0.809	65	539	0.108	515	92	0.848	229	576	0.284
	334	119	0.737	67	527	0.113	509	144	0.779	121	592	0.17
	328	125	0.724	104	451	0.187	417	119	0.778	95	675	0.123
	350	97	0.783	80	545	0.128	412	108	0.792	133	531	0.2
	428	100	0.811	59	621	0.087	345	129	0.728	0	0	
	441	107	0.805	66	640	0.093	492	76	0.866	157	506	0.237
	355	83	0.811	103	608	0.145	419	79	0.841	138	476	0.225
	430	90	0.827	76	449	0.145	495	118	0.808	112	438	0.204
	376	111	0.772	108	768	0.123	444	131	0.772	132	650	0.169
	353	117	0.751	71	554	0.114	490	146	0.77	176	456	0.278
Av	369.5	102	0.783	79.9	570.2	0.124	453.8	114.2	0.798	129.3	490	0.21
						0.876						0.79

Unsig	BL C2	BR C2	CP(L)	BL C2	BR C2	CP(L)	BL C2	BR C2	CP(L)	BL C2	BR C2	CP(L)
	192	313	0.38	558	106	0.84	120	336	0.263	512	173	0.747
	167	463	0.265	663	63	0.913	203	296	0.407	463	145	0.762
	173	376	0.315	528	81	0.867	141	346	0.29	468	119	0.797
	217	406	0.348	637	64	0.909	121	281	0.301	677	146	0.823
	184	407	0.311	637	49	0.929	88	421	0.173	0	0	
	176	448	0.282	712	53	0.931	118	452	0.207	726	130	0.848
	204	426	0.324	801	38	0.955	97	434	0.183	392	40	0.907
	125	457	0.215	644	24	0.964	146	409	0.263	418	110	0.792
	152	616	0.198	758	41	0.949	111	337	0.248	161	6	0.964
	215	630	0.254	679	57	0.923	120	469	0.204	0	0	
Av	180.5	454.2	0.289	661.7	57.6	0.918	126.5	378.1	0.254	381.7	86.9	0.83
						0.082						0.17

Appendix 4: Individual data from Experiment 4, sum of responses on the left and right, of the last five sessions across components, for the Independent Scheduling group (Pigeons 185-188)

Prob/Delay		185		186		187		188	
	Comp	BL	BR	BL	BR	BL	BR	BL	BR
33% 67% S	Red	1995	2296	7701	1328	1908	1634	3933	1334
	Grn	1204	1764	432	7590	384	2668	1570	3223
	Wht	1614	2407	1333	5819	1349	2540	1729	2668
67% 33% S	Red	5099	1100	9574	497	4056	284	8208	134.5
	Grn	2275	1690	1154	5271	1254	2415	2219	1972
	Wht	4183	1380	5010	2928	3826	882	3702	1507
17% 83% S	Red	1681	2807	2288	5065	953	2208	3304	1420
	Grn	991	3128	357	7417	704	2527	597	4565
	Wht	1813	2591	1179	5505	1359	2647	1779	2968
83% 17% S	Red	7053	553	15532	106	3389	55	8820	8
	Grn	2748	1656	4504	3542	2598	8	5949	288
	Wht	4036	1295	7926	1177	2105	15	7580	215
33% 67% US	Red	2284	3011	5485	1336	2876	755	1981	1017
	Grn	350	5967	18	8065	694	2202	63	3770
	Wht	1769	3370	181	5978	1077	1271	1195	2018
67% 33% US	Red	10373	437	8252	510	4984	311	5495	120
	Grn	1499	3672	4067	4001	1316	1250	1054	1530
	Wht	3482	2294	5222	2622	2305	637	2592	1081
17% 83% US	Red	1572	2927	2963	3264	1106	2026	1289	1588
	Grn	243	4708	27	11627	50	5613	33	4344
	Wht	690	4220	74	7956	294	3665	277	3889
83% 17% US	Red	12348	28	13938	25	7173	78	5042	98
	Grn	3099	1284	4247	2542	3916	166	2583	303
	Wht	11518	216	10781	342	4828	205	4239	223

Appendix 5: Individual data from Experiment 4, sum of responses on the left and right, for last five sessions across components, for the Non-Independent Scheduling group (Pigeons 161-164)

Prob/Delay		161		162		163		164	
	Comp	BL	BR	BL	BR	BL	BR	BL	BR
33% 67% S	Red	2523	2517	4690	1638	1325	4675	5323	1240
	Grn	1149	3381	811	8364	462	6322	397	8883
	Wht	2116	3265	1890	5028	733	5539	687	6086
67% 33% S	Red	5660	1522	7649	380	7778	769	7452	383
	Grn	3645	1971	4124	1723	2224	3208	1699	5265
	Wht	5960	1725	6566	1006	6046	1116	4425	2530
17% 83% S	Red	717	6933	4416	2151	414	3683	813	5344
	Grn	378	5906	469	10089	340	9123	249	9122
	Wht	529	6934	1272	5682	501	5830	450	6432
83% 17% S	Red	9245	722	12181	271	6098	425	6407	324
	Grn	4571	1619	4940	2111	6394	732	4208	1159
	Wht	6739	1295	7594	867	7540	532	5510	864
33% 67% US	Red	5046	2446	5229	589	4493	840	2702	2436
	Grn	823	6606	192	9356	163	7075	296	9458
	Wht	733	5903	1698	5587	2572	2402	568	6294
67% 33% US	Red	10640	172	8008	216	8985	88	8072	752
	Grn	2394	2636	2231	2371	1954	1966	1538	5402
	Wht	2448	1975	3774	939	8245	308	4792	1507
17% 83% US	Red	727	5106	694	7189	292	6657	981	4299
	Grn	143	11889	135	10831	195	14930	159	10634
	Wht	307	6531	173	7318	154	9679	456	7229
83% 17% US	Red	10445	159	11022	112	17281	120	8242	284
	Grn	3972	2177	7131	713	6645	356	6204	1140
	Wht	5780	477	13268	166	12285	157	7573	637

Appendix 6: Individual data from Experiment 5, sum of responses on the left and right, for last five sessions across components, for the Independent Scheduling group (Pigeons 195-198)

Prob/Mag		195		196		197		198	
	Comp	BL	BR	BL	BR	BL	BR	BL	BR
33% 67% S	Red	3557	1345	7274	496	2349	2460	2309	1635
	Grn	1760	3658	2404	1994	3015	5387	2470	4725
	Wht	1608	3242	2505	2114	2032	4492	2915	3093
67% 33% S	Red	3216	568	6101	1050	5795	1291	5017	1790
	Grn	2022	1486	2487	2114	6171	2596	5079	3028
	Wht	3220	836	2659	2056	5881	2156	4935	2234
17% 83% S	Red	2881	1203	784	2462	242	5138	2563	3449
	Grn	1091	4281	361	6171	15	10650	1464	7859
	Wht	1766	2795	746	4282	88	6371	1006	7033
83% 17% S	Red	5421	440	8623	440	9522	582	16816	179
	Grn	2297	4133	3455	1389	5806	620	7785	1287
	Wht	5098	1055	4262	1310	7516	217	7296	896
33% 67% US	Red	2025	1361	2307	3613	4170	2225	3922	2213
	Grn	187	6017	397	7062	726	8323	1807	5876
	Wht	870	2828	950	6386	1147	5508	1908	4013
67% 33% US	Red	4398	102	6436	606	8228	687	5124	1065
	Grn	1329	1450	4586	1331	4699	2693	4520	2180
	Wht	2812	611	5846	962	3887	2060	3140	2302
17% 83% US	Red	1400	1363	457	5443	2312	3042	2510	1965
	Grn	74	5365	12	7461	403	8458	201	5548
	Wht	115	4129	64	8233	561	6860	474	5332
83% 17% US	Red	5248	21	13235	70	11194	425	4344	319
	Grn	2241	408	6651	431	8600	1207	2751	269
	Wht	4774	112	9244	305	7344	971	3190	275

Appendix 7: Individual data from Experiment 5, sum of responses on the left and right, for last five sessions across components, for the Non-Independent Scheduling group (Pigeons 165-168)

Prob/Mag		165		166		167		168	
	Comp	BL	BR	BL	BR	BL	BR	BL	BR
33% 67% S	Red	1882	3036	4755	2116	3885	1464	1524	2526
	Grn	1282	5264	1341	4295	849	3147	839	4076
	Wht	1749	3254	2077	3494	1987	2104	1677	3319
67% 33% S	Red	2721	568	9745	1264	4762	431	3033	1363
	Grn	4821	1041	3782	2198	1449	2200	2150	1687
	Wht	3696	1236	7738	983	3632	1125	3848	1406
17% 83% S	Red	1076	4749	4364	1598	629	5182	785	5117
	Grn	1405	3644	514	5797	593	2960	796	3688
	Wht	1417	3350	1329	4374	775	2713	960	4081
83% 17% S	Red	6739	769	9374	980	2977	1044	4274	704
	Grn	5959	1134	2420	4016	2225	1772	3117	830
	Wht	6254	949	6442	1402	4260	839	4747	511
33% 67% US	Red	1359	5792	305	618	1785	3269	705	4359
	Grn	379	11060	386	3258	329	3701	598	4369
	Wht	891	6736	472	1768	342	3918	558	5048
67% 33% US	Red	9628	748	2794	341	8949	243	5076	1371
	Grn	4419	2645	1240	388	2974	1287	2191	2461
	Wht	5720	1341	2828	178	3845	702	3235	2417
17% 83% US	Red	729	4197	1729	4954	804	3123	401	7095
	Grn	165	12138	410	9529	220	5182	166	6083
	Wht	254	8303	465	9506	489	4857	364	8808
83% 17% US	Red	11628	363	4431	29	7344	174	7776	264
	Grn	7880	1109	2050	75	4218	729	5445	343
	Wht	10102	439	4417	42	6462	345	7438	196